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DEVELOPMENT OF FASTENER TECHNOLOGY FOR BERYLLIUM POINT DRIVE BOLTS AND BLIND FASTENERS (Final Report)

Prepared under Contract No. NAS 8-20158 by
James J. Glackin, Edward F. Gowen, Jr., and
Cornelius J. Keeney, Jr.

SPS LABORATORIES

For

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

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(Final Report)

Contractor's Report dated May 31, 1967

By

James J. Glackin, Edward F. Gowen, Jr,
and Cornelius J. Keeney, Jr.

Prepared under Contract No. NAS 8-20158 by
SPS LABORATORIES
Jenkintown, Pa.

For

Manufacturing Engineering Laboratory

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

FOREWORD

The work accomplished to generate the information included in this report was performed under Contract NAS8-20158 by SPS Laboratories of Standard Pressed Steel Co., Jenkintown, Pennsylvania.

Mr. Edward F. Gowen, Jr. was Program Manager for SPS Laboratories with technical project coordination directed by Mr. James J. Glackin, Mr. Gregory Gries, and Mr. Cornelius J. Keeney.

The work was under the technical direction of Mr. Carl M. Wood of the Manufacturing Research and Technology Division, Manufacturing Engineering Laboratory, George C. Marshall Space Flight Center, Marshall Space Flight Center, Alabama 35812.

Appreciation for valuable technical assistance is gratefully acknowledged to Mr. Gerhard Meyer and Mr. Richard Walker, Mechanical and Material Research Department, Mr. William Grimes, Research Services Department, and Mr. William Eyre, Pilot Manufacturing Laboratory of the SPS Laboratories.

ABSTRACT

This report is the Final Report for Contract NAS8-20158. The work was initiated by the George C. Marshall Space Flight Center to find possible weight reductions for the Saturn V Thrust Structure. This investigation covered the usage of beryllium fasteners. Goals of the program were to develop, produce and test optimum configuration beryllium prestressed fasteners (point-drive bolt and twist-off nut) and beryllium blind fasteners. The investigation was conducted in four phases.

Phase I was a feasibility study which showed that prestressed fasteners and blind fasteners of beryllium were feasible.

In Phase II, a beryllium prestressed fastener and a beryllium blind fastener were developed for use to 800°F temperature. The program established fastener configuration, selection and procurement of materials, determination of process of manufacture, determination of process controls and tooling.

Phase III consisted of the evaluation of five grades of beryllium materials and established the optimum alloy for fabrication which exhibited the most desirable mechanical properties. Beryllium Corporation XT-20 material was selected as the optimum alloy.

Phase IV consisted of the fabrication and testing of a production size lot of prestressed fasteners. It was concluded that the material used to produce the finished bolts for this contract would not be acceptable by Standard Pressed Steel Co. standards for the manufacture of high reliability bolts. Recent work, however, has shown that the XT-20 material could be used to manufacture satisfactory hexagon nuts.

It should be noted that a forgeable grade beryllium for fastener application has recently been developed by the Brush Beryllium Co. Information and test data on this material are presented.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (continued)

LIST OF ILLUSTRATIONS (continued)

LIST OF ILLUSTRATIONS (continued)

LIST OF ILLUSTRATIONS (continued)

LIST OF ILLUSTRATIONS (continued)

SECTION I

INTRODUCTION

This contract was initiated to find possible weight reductions for the Saturn V Thrust Structure through the use of light-weight, high strength materials for mechanical fasteners. The material chosen for investigation was beryllium as high strength fasteners of titanium and steel were well covered in other work conducted for the National Aeronautics and Space Administration.

Beryllium has the structure advantages of high strength-to-weight ratio, a high Young's Modulus and high fatigue life. The disadvantages of the material are the low ductility and attendant notch sensitivity, poor crack propagation characteristics and high initial cost. Although the cost of beryllium fasteners would be high, the possible cost savings through weight reduction would more than offset the initial cost. Because of the high cost of weight on aerospace vehicles it was imperative that beryllium be investigated for use as structural fastener material.

This program was initiated to investigate the usage of beryllium fasteners. Goals of the program were to develop, produce, and test optimum configuration beryllium prestressed fasteners (point drive bolt and twist-off nut) and blind fasteners with minimum mechanical properties of:

Ultimate Tensile Strength	- 75,000 psi
Ultimate Shear Strength	- 65,000 psi
Endurance Limit @ 10^6 Cycles	- 45,000 psi

The approach to the program was in four phases:

- Phase I - Feasibility Study
- Phase II - Development
- Phase III - Evaluation of Beryllium Alloys
- Phase IV - Fabrication and Testing

Phase I covered the history of beryllium fasteners and materials, the state-of-the art in the production of beryllium fasteners and problem areas that may be encountered in the production of beryllium fasteners. The investigation showed that semi-blind and blind fasteners of beryllium were feasible and a planned approach for the development of these fasteners was presented.

Introduction (continued)

The Phase II program established fastener configuration, selection and procurement of materials, determination of process of manufacture, determination of process controls, tooling and the establishment of a test program for Phase IV.

Phase III consisted of the evaluation of five grades of beryllium materials and established the optimum alloy for fabrication which exhibited the most desirable mechanical properties.

Phase IV consisted of the fabrication and testing of a production size lot of prestressed fasteners. The problems associated with fabrication and test results are presented.

SECTION II

SUMMARY

A. Feasibility Study

The study showed that essentially no research and development work in beryllium fasteners was conducted since 1961. Prior to 1961, the most extensive development of beryllium fasteners was done by SPS Laboratories under a contract, awarded by the Air Force in 1959. (Ref. 1) The results of this contract showed that hexagon head shear bolts of beryllium could be manufactured with tensile and shear strengths of 75,000 psi and 65,000 psi respectively. These properties were subsequently used to establish the target properties for this program. The materials used were provided by the Beryllium Corporation and Brush Beryllium Company.

The study further showed that standard manufacturing equipment was used for the fabrication of beryllium fastener. This was modified only by the addition of suitable exhaust systems to keep the toxic materials to a minimum in the work area. Head configurations were formed by hot forging and threads by a single rolling operation.

Aside from this investigation and some in-house work conducted by Standard Pressed Steel Co. (Ref. 2), not much work was concentrated in the area of beryllium threaded fasteners. Of the prominent aero-space manufacturers contacted, only the Precision Fastener Division of Standard Pressed Steel Co. quotes, makes and sells beryllium fasteners.

It was concluded from the study that beryllium prestressed fasteners and blind fasteners were feasible provided previously investigated materials could be reproduced by the suppliers.

B. Development of Beryllium Fasteners and Evaluation of Beryllium Alloys

The development of prestressed and blind fasteners, and the evaluation of beryllium alloys were run concurrently. Approximately twelve materials were investigated. None of the materials exhibited the forging characteristics required to produce

B. Development of Beryllium Fasteners and Evaluation of Beryllium Alloys (continued)

a crack-free head. Since a forgeable grade was not available for fastener application, forward extrusion of a head was investigated. The process proved successful. Berylco XT-20 material was established as the optimum alloy for fabrication which exhibited the most desirable mechanical properties.

Although forward extrusion was eventually used, it did present certain limitations or drawbacks when compared to forging or hot upsetting a head. These were:

1. Significantly weaker head strength
2. Limited bolt lengths
3. Confined to simple head configurations
4. Exceptionally high scrap rates.

With the establishment of process of manufacture and optimum material, the prestressed fastener illustrated in Figure 1 and the blind fastener illustrated in Figure 2 were developed. Typical properties are listed in Table I.

The prestressed fastener consists of a beryllium bolt with a hexagon recess on the thread end for holding during installation; and the nut is a collar type nut of stainless steel which is grooved to permit the wrenched element to shear off at a predetermined torque.

The use of stainless steel for the collar permits a utilization temperature to 800°F. Optimum hexagon recess design and notch geometry for #10, 1/4 and 5/16 inch diameter fastener assemblies were developed to produce adequate clamping forces after installation.

The blind fastener can be inserted and driven from one side of the work. The head or collar on the blind side is stainless steel while the sleeve and core bolt are beryllium. It requires a two step installation in which a collar-nut combination is swaged over the beryllium sleeve with a threaded steel mandrel. After swaging, the mandrel is disengaged and replaced with a beryllium core bolt.

B. Development of Beryllium Fasteners and Evaluation of Beryllium Alloys (continued)

Initially, the goal of the program was to develop a blind fastener which could be installed in a single operation. However, attempts to develop the various types of this fastener system failed for the following reasons:

1. The toxicity problem and high cost of input material associated with beryllium did not permit the use of a break-off device for establishing seating torques.

2. The use of a point drive bolt for swaging the collar resulted in failure of the hexagon recess during installation.

3. High sleeve rejection rates were associated with the use of tapped beryllium sleeves.

4. It was not feasible to manufacture an expandable sleeve from beryllium.

5. High installation forces were required for the press-nut type of fastener, and therefore, eliminated it for usage with thin beryllium sheet.

Finally, valuable information and experience were gained in the fabrication and testing technology for beryllium fasteners. However, the finished fasteners produced by the contract would not be acceptable by Standard Pressed Steel Co. standardsfor high reliability fasteners. It is expected that the fasteners developed in this program could be produced with high reliability from the Brush Forgeable Grade Beryllium. They could be produced with properties meeting or exceeding the goals of this contract. It was unfortunate that this material was developed after the completion of this program.

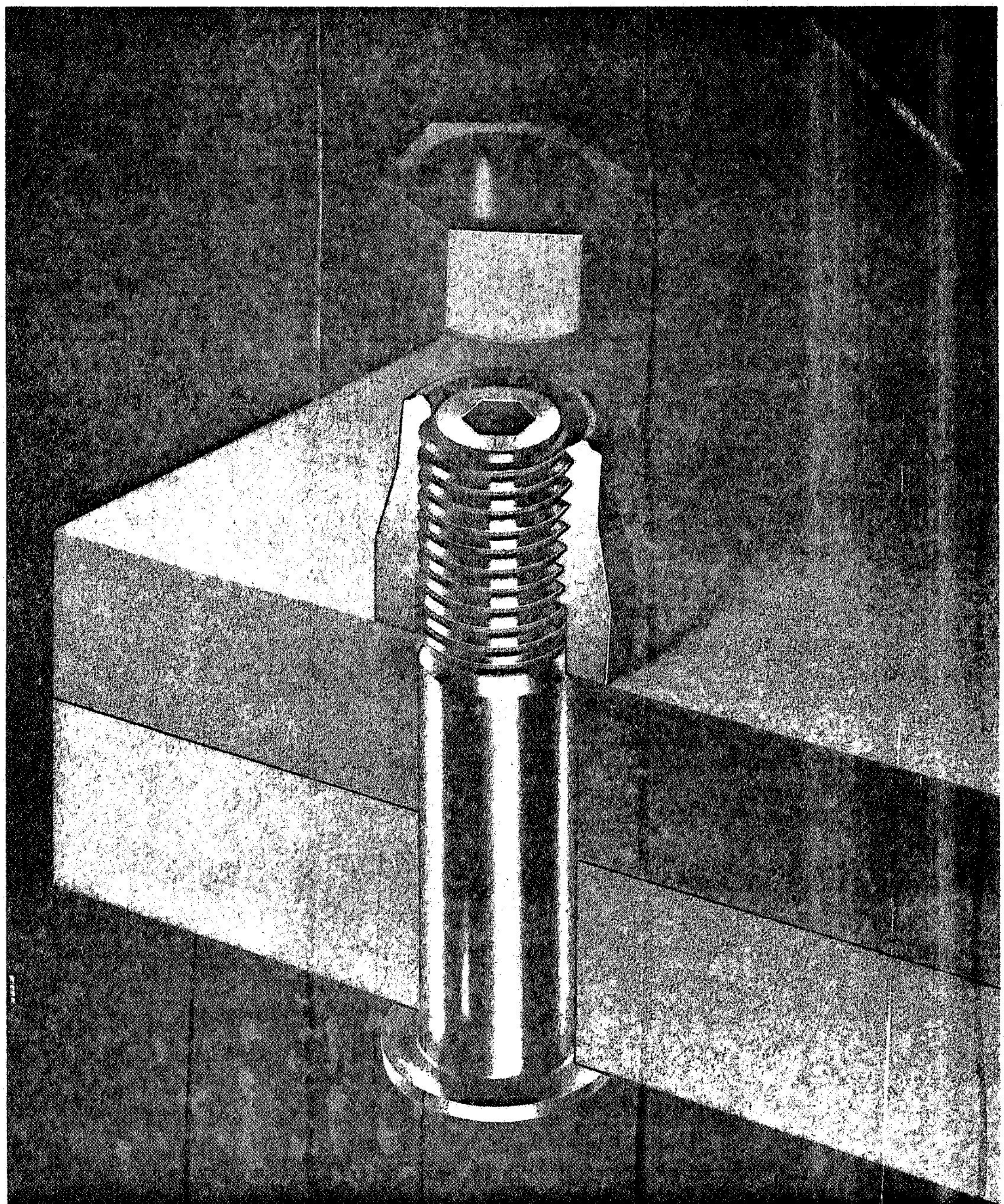

Figure 1. Illustration of Prestressed Fastener System

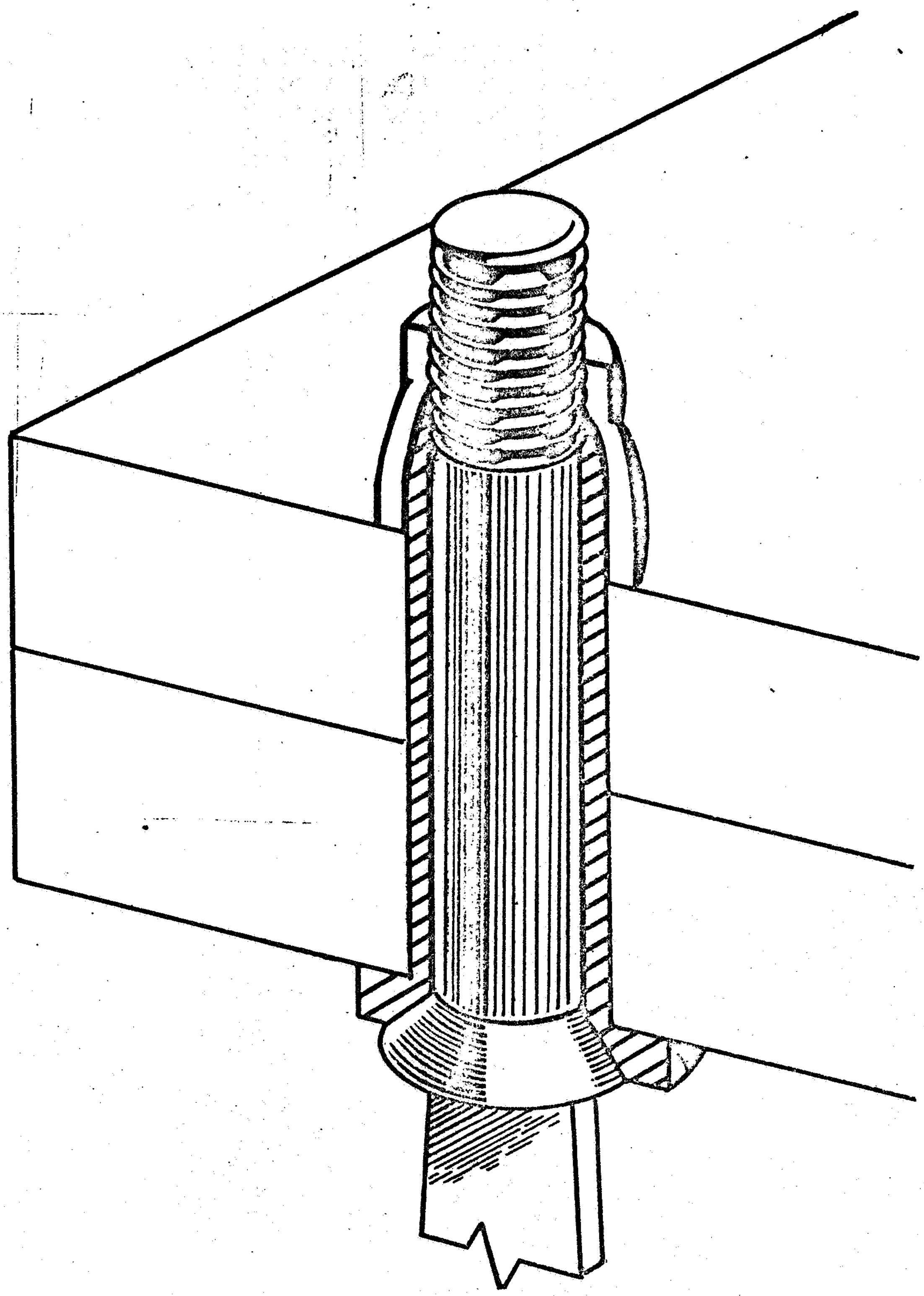

Figure 2. Illustration of Blind Fastener System

TABLE I

TYPICAL MECHANICAL PROPERTIES OF BERYLLIUM PRESTRESSED AND BLIND FASTENERS

		Prestressed	Blind
Ultimate Tensile Strength - Psi			
	@ R. T.	75, 000	50, 000
	@ 800°F	45, 000	40, 000
Double Shear Strength-Psi			
	@ R. T.	65, 000	40, 000
	@ 800°F	40, 000	25, 000
Lap Joint Shear Strength -Psi			
T/D=0. 526	@ R. T.	63, 000	Not Conducted
	@ 800°F	38, 000	Not Conducted
Butt Joint Shear Strength -Psi			
T/D=0. 526	@ R. T	35, 000	Not Conducted
	@ 800°F	27, 000	Not Conducted
Tension-Tension Fatigue Max. Stress - 45, 000 Psi R=0. 1 cycles @ R. T.		1×10^6	Not Conducted

R. T. - Room Temperature
T/D - Sheet Thickness/Fastener Diameter
R - Ratio of Minimum Stress/Maximum Stress

SECTION III

FEASIBILITY STUDY

A study was conducted to determine the state-of-the art in producing beryllium fasteners with reliable properties. Special consideration was placed on thefeasibility for the manufacture of beryllium blind rivets and prestressed fasteners with particular emphasis on the blind rivet. The study was confined to the following areas:

Beryllium Fastener History
Production of Beryllium Fasteners (State-of-the-Art)
Problem Areas to be Resolved in the Production of Beryllium Fasteners

A. BERYLLIUM FASTENER HISTORY

The first research on mechanical fasteners of beryllium material was conducted at SPS Laboratories during 1957-1958. This work concerned itself with thread properties of a limited amount of commercially pure beryllium. This was a natural extension from titanium mechanical fasteners which were being used in great quantities at that time. There was no better beryllium rod stock for fasteners than the commercially pure beryllium available at that time.

Early in 1959, the Fabrication and Components Branch in the Manufacturing and Materials Technology Division of AMC Aero Systems Center, Wright-Patterson Air Force Base, Ohio took an interest in the possibilities of using beryllium for light weight fasteners. A Request for Proposal was issued with the subsequent award of a beryllium fastener development contract to SPS Laboratories.

The result of this contract, AF33(600)-39728, was Report No. AMC TR 60-7-807 showing the successful development of hexagon head shear bolts and their mechanical properties. These properties were used to establish the target properties for this program. The beryllium materials used in the Air Force program were provided by Beryllium Corporation and Brush Beryllium Company.

A. Beryllium Fastener History (continued)

The next program on beryllium fasteners was SPS Laboratories in-house financed work which resulted in SPS Laboratories Report No. 397, "Beryllium Shear Bolts Flush Head BFT 12 and BFH 12, Protruding Head BHS 12-60,000 Psi Minimum Shear Strength". Data on hexagon head and 100° flush head shear bolts were presented on three heats of beryllium material. The strength-to-density ratio of these bolts was over 1,100,000 psi/pound/cubic inch in tensile and almost 1,000,000 psi/pound/cubic inch in shear. These strength values exceeded those of available 4Al-4 Mn titanium and alloy steel bolts. Both titanium and steel have moved to higher strengths since 1961 and are again ahead of beryllium.

After the 1961 work very little research and development work in beryllium fasteners was conducted. Some work was done on tapping beryllium nuts and SPS K-2 Lubricant was found to be a very successful anti-gallant and lubrication for the tightening of beryllium nut and bolt combinations. Some production quantities of fasteners were sold for nuclear engines and the Agena B Program, but not much else was accomplished. Current beryllium structural test programs have not included beryllium fasteners for their weight saving capability primarily due to high cost and non-availability of a variety of beryllium structural fasteners.

B. PRODUCTION OF BERYLLIUM FASTENERS

To determine the state-of-the-art in the production of beryllium fasteners, several areas were investigated. The specific areas investigated were the beryllium suppliers and their available materials, beryllium fastener manufacturers, manufacturing procedures and tests to determine the reliability of a fastener.

1. Beryllium Suppliers

At present, there are four companies capable of producing beryllium materials for fastener fabrication. These companies are:

1. Beryllium Suppliers: (continued)

a. Beryllium Corporation (Berylco)
Hazleton, Pennsylvania 18201

b. The Brush Beryllium Company
17876 St. Clair Avenue
Cleveland, Ohio 44110

c. Beryllium Metals and Chemical Corp. (Bermet)
500 Fifth Avenue
New York, New York 10036
A subsidiary of Lithium Corp. of America

d. General Astrometals Corp.
320 Yonkers Avenue
Yonkers, New York 10701

2. Beryllium Materials

During the course of the Air Force Beryllium Bolt Program in 1960, Berylco and Brush both supplied special grades which could be forged and thread rolled. These had base material properties of approximately 90,000 psi ultimate tensile and 65,000 psi shear strengths.

Since the Air Force Program, neither Berylco nor Brush have concentrated any effort in the development of an improved beryllium fastener material primarily because a demand did not exist. Furthermore, Berylco indicated that they could not guarantee to duplicate the same material previously evaluated. Brush expressed that they could guarantee the shear strength while Bermet and General Astrometals were willing to quote on a best efforts basis.

Berylco suggested three grades of beryllium, but one of these, a special forging grade, did not meet the minimum target requirements of 65,000 psi shear strength. One of the lots called PX-12 was to be a duplicate of the high strength grade used in the 1960 Air Force Program. This grade had a maximum beryllium oxide content of 1.2 percent. The third grade

2. Beryllium Materials (continued)

suggested was a low oxide, cast material which would be extruded and drawn to the size needed for this program. Mechanical properties were to be on a best effort basis.

In addition to the straight beryllium grade, Berylco offered data on Lockalloy extrusions showing very low strengths. Because of the high beryllium content, approximately 60 percent, the same protective machining methods were required as for standard beryllium grades. Ductility and cost were the same as for standard beryllium. Therefore, Lockalloy did not offer any distinct advantage over standard beryllium and was not considered for this program.

Brush Beryllium Company had nothing new to offer for improved beryllium fastener material. They quoted on supplying material as used in the SPS Laboratories 1960 Air Force program but with a guaranteed shear strength of 65,000 psi.

Bermet had little history in high strength structural beryllium, but to be considered for this program they went into a development program in conjunction with Nuclear Metals, division of Textron, Inc., West Concord, Massachusetts. They would extrude three grades from 1 1/2 inch diameter by 6 inch billets. Twenty-two to one reduction ratios would be used to get to final stock size of .290 inches. They agreed to supply one foot samples of two of the grades to SPS Laboratories.

General Astrometals was another company which had no prior experience in supplying beryllium fastener stock. They offered to supply material on a developmental, best effort basis. In order to participate in the program, General Astrometals supplied a 48 inch sample heat of 3/4 inch round material.

3. Beryllium Fastener Manufacturers

At the beginning of this program several prominent aerospace fastener manufacturers were contacted to determine who were manufacturing beryllium fasteners and what other information might be offered. Of the firms contacted only the Precision Fastener Division of Standard Pressed Steel Co. quotes, makes and sells beryllium fasteners. The companies contacted were:

Briles Manufacturing Co.
E. Grand & Kansas Ave.
El Segundo, California
Comment - Do not plan to make and no experience.

Camcar Division of Textron
18th & Kishankee Ave.
Rockford, Illinois
R. R. Blomberg
Comment - Do not make now, but looking for possible future product.

Hi Shear Corporation
2600 West 247th Street
Torrance, California
Mr. E. Hatter
Comment - Do not make now or plan to in the immediate future.

Standard Pressed Steel Co.
Precision Fastener Division
Jenkintown, Pa.
Comment - Catalogue item

Voi-Shan Manufacturing Co.
8463 Higuera St.
Culver City, California
Mr. D. Anderson
Comment - Not making now, but did in-house development 3 years ago.

4. Fastener Configuration

The only company that had beryllium bolts as a catalogue item was the Precision Fastener Division of Standard Pressed Steel Co. These were hexagon head shear bolts and the 100° flush head bolt with either Torque Set or Hi Torque drive.

There were no blind bolts, rivets or nuts available on the market.

5. Manufacturing of Fasteners

The most comprehensive evaluation of threaded fasteners fabricated from beryllium material was conducted by Standard Pressed Steel Co. for the Air Force under contract AF33(600)-39728 (Ref 1). Aside from this evaluation and some in-house work conducted by Standard Pressed Steel Co., the investigation showed that very little work has been concentrated in the area of beryllium threaded fasteners. Nevertheless, the reported results of the evaluation contained valuable information for the fabrication and the testing of beryllium fasteners. They included the following:

Available materials
Establishment of inspection methods for bar stock
Establishment of manufacturing methods for beryllium

a. Available Materials

There is presently available beryllium material which can be fabricated into fasteners. Ultimate strengths of these materials are on the order of 100,000 psi.

b. Manufacturing

Standard manufacturing equipment was used for the fabrication of beryllium fasteners. This was modified only by the addition of suitable exhaust systems to keep the toxic materials to a minimum in the work area.

5. Manufacturing of Fasteners (continued)

b. Manufacturing (continued)

NAS 464 configuration bolts were fabricated from Berylco HPA ground, extruded bar stock and Brush extruded QVM bar stock.

1. Forging

Optimum forging temperature for the forming of hexagon heads was 1450°F to 1500°F. At temperatures lower than 1450°F cracks were found in the head and often the head did not completely fill out. At the higher temperatures above 1600°F the material burned, formed head cracks, and chipped on the hex corners because of oxidation. The forging dies used were the same as those for a steel NAS 464 bolt.

2. Machining

Turning, center drilling, pointing and thread chasing were accomplished on a South Bend ten-inch engine lathe. K-6 carbide tools were used for these operations; and for the turning operation, a feed of 120 surface feet per minute was employed. The speed could have been increased but optimum chip removal required this lower turning rate. In any event, the machining of beryllium presented no problem other than health hazards which are adequately controlled by proper exhaust systems.

3. Grinding

Grinding was accomplished on Brown and Sharpe Grinders. Specimens and bolts were ground on centers but without a coolant to facilitate dust collection by the exhaust system. The heat generated was insufficient to cause cracking. The material could be centerless ground using the mandatory safety precautions.

5. Manufacturing of Fasteners (continued)

4. Thread Rolling

The rolling of threads on beryllium material was accomplished without any difficulty in the fabrication of beryllium bolts. They would be definitely preferred over bolts with machined threads. The residual stresses induced by thread rolling greatly increased the mechanical properties of beryllium bolts.

Thread properties were also markedly increased by increasing the root radius and decreasing the thread depth from 83 1/3% to 55%. The tensile strength of bolts with 55% rolled threads was 50% higher than 55% machined threads.

Thread rolling of ground beryllium bolt blanks was accomplished with an A-22 Reed Cylindrical Die Thread Rolling Machine employing three dies. Threads were formed by die pressure exerted on the ground blanks. The thread profile was in accordance with NAS 464 drawing. Dust collection units were not required because there was no metal removal, just metal movement.

5. Surface Treatment (Etching)

Surface treatment or etching of finished bolts greatly increased shear strength and fatigue life. Double shear strength of unetched ground blanks was 20,000 psi compared to 60,000 psi for ground and etched blanks. Brittle failures were noted for unetched blanks, while ductile failures were noted for the treated blanks. Hence, the surface treatment of finished beryllium bolts is a prerequisite for optimum properties. The etchant used for surface treatment was:

100 grams chromic acid (anhydride)
77 milliliters phosphoric acid
10 milliliters concentrated sulphuric acid
50% by volume water

6. Mechanical Properties

a. Double Shear

The double shear strength of the shanks of beryllium bolts was over 60,000 psi, or more than 65% of the strength of the base material. Steel and titanium bolts have a double shear strength of only 60% of the strength of the base material. On a strength per density basis the beryllium bolts were equivalent to alloy steel bolts of about 400,000 psi and 4Al-4Mn titanium bolts of about 200,000 psi.

The program substantiated that the bolts had to be surface-treated to give a ductile double shear failure. The surface treatment also doubled the shear strength when compared to ground beryllium.

On a strength-to-weight basis, the surface treated beryllium bolts were 1.6 times higher than titanium bolts with a 172,000 psi tensile strength and 2.6 times higher than steel bolts heat treated to about 200,000 psi. In other words, beryllium fasteners would have to be replaced by titanium bolts weighing 1.6 times as much or by steel bolts weighing 2.6 times as much to get the same strength in the transverse direction.

b. Tensile

The ultimate tensile strength of the beryllium bolts was over 70,000 psi with failure occurring at the thread runout. The strength of the bolts exceeded 70% of the strength of the base material. This is acceptable for shear configurations. There is no evidence available to indicate that the 70% proportion would hold true for stronger beryllium materials.

On a strength-to-weight comparison, the beryllium bolts exceeded the ultimate tensile strength of similar configurations of titanium by 10% and steel by over 60%. However, it should be noted that tension bolts fabricated from beryllium would not be recommended at this time because of the high degree of notch sensitivity for this material.

6. Mechanical Properties (continued)

c. Fatigue

The fatigue endurance limit of the beryllium fasteners was 45,000 psi for the Berylco bolts and 50,000 psi for the bolts fabricated from Brush material. This compares to 60,000 for titanium and 20,000 psi for steel bolts.

The endurance limit of beryllium was twice titanium and nearly ten times steel when compared on strength-to-weight ratios. This means twice the weight of titanium and ten times the weight of steel would be required to get the same clamping force as provided by beryllium fasteners.

The S-N curves on beryllium fasteners are very flat and indicate a wide variance of results above the endurance limit. Since in most cases the load level above the endurance limit exceeded the yield strength of the bolt, wide scatter would have to be expected. The use of beryllium fasteners would have to be confined to loads under the endurance limit to get high reliability.

d. Torque-Tension

The load induced in the beryllium bolts for a given torque was less than that induced in steel or titanium bolts.

e. Ductility

The base beryllium material exhibited little longitudinal elongation. The Brush material had 3% and the Berylco had 6.5%. This is less than desirable for full control during forging. The reduction of area was 5.6% for the Brush material and 10.0% for the Berylco material.

The two factors, elongation and reduction of area, together indicate that beryllium is a brittle material. Because of the brittleness inherent in the material, extra precautions had to be taken in manufacturing and testing the bolt.

7. Inspection Methods

a. Bar Stock

For incoming material, the two most successful methods consisted of fluorescent penetrant inspection and dye penetrant inspection with the former proving the easiest and best method. Very tight cracks could be determined by these methods. Both methods require a surface treatment of a light etch prior to inspection. This is to remove any material that may be covering defects such as cracks and seams since the metal beryllium has a tendency to smear during machining. The etchant used was the same as that listed under surface treatment. The inspection processes were as follows:

1. Fluorescent Penetrant Inspection

   1. Etch .003 inches per surface
   2. Dip in solvent for 25 minutes
   3. Clean off solvent
   4. Dip in developer for 10 minutes
   5. Dry
   6. Inspect under black light

2. Dye Penetrant Inspection

   1. Etch .003 inches per surface
   2. Coat piece with red visible penetrating dye (Met-L-Chek E150)
   3. Set for at least 25 minutes
   4. Remove dye with dye remover - emulsifier
   5. Wipe completely dry
   6. Spray with light coat of spirit developer
   7. Check for red indications on white surface

b. In Process Inspection

All critical dimensions were inspected after every operation. Extensive tests were made after forging because of the metallurgical changes introduced by forging. These tests were:

7. Inspection Methods (continued)

b. In Process Inspection (continued)

1. Fluorescent penetrant inspection. The post emulsification method to expose any cracks developed during forging.

2. Macro examination of metal flow characteristics.

3. Micro examination of grain structure at head area.

c. Final Inspection

Upon completion of manufacture, the bolts were inspected for dimensional conformance to appropriate drawings particularly the threads for a Class 3A fit. Finally, the bolts were checked for cracks by the fluorescent penetrant method.

SECTION IV

EVALUATION OF BERYLLIUM MATERIALS

Evaluation of beryllium alloys and the development of beryllium fasteners which constituted Phase II and III were run concurrently. The evaluation of beryllium materials consisted of selection and procurement of materials which showed potential for meeting the minimum bolt properties of:

Ultimate Strength	- 75,000 psi
Shear Strength	- 65,000 psi
Endurance Limit	- 45,000 psi

A. Selection and Procurement of Materials

Initially five grades of material were selected for evaluation. These selected materials and suppliers are listed in Table I. Listed also are the material specifications, diameters, extrusion reduction ratios, and extrusion temperatures. Table II lists the mill chemical analysis for the five grades. The materials were selected because they either showed favorable properties in prior programs or potential for meeting the aforementioned minimum properties.

Because a crack free head could not be forged on any of these materials, several other grades were investigated for forgeability characteristics during the course of Phase III. These grades were submitted in sample lots by the suppliers and are discussed under the Fabricability Investigation in Section VII.

It should be noted at this point, however, that a forgeable grade of beryllium has been developed by the Brush Beryllium Company for fastener application. Unfortunately, the development of this grade of material came at a time when the work in this contract was completed. Since the development of this forgeable grade of material was conducted in a cooperative program with SPS Laboratories, all significant results are incorporated in this report. Fasteners of this material are presently being manufactured in production quantities by the Precision Fastener Division of Standard Pressed Steel Co.

B. Material Properties

Listed in Tables III through VII are the material properties obtained for the selected beryllium materials evaluated. Table VIII lists the material and fastener properties of the forgeable Brush material recently generated by SPS Laboratories. Included in the tables are the test results submitted by the respective suppliers.

All grades tested met the minimum ultimate tensile strength of 75,000 psi. Ductility in most cases could not be determined because the specimens either fractured into several pieces or they fractured outside the gage length. In any event, since the materials exhibited poor forging characteristics for fastener application, further determination of material tensile properties was discontinued.

The results of the double shear tests indicated that with the exception of the Brush SP 200-C material, all would meet the minimum shear requirements of 65,000 psi. The maximum shear strength of the Brush SP 200-C material was 45,000 psi. Subsequent variations in preparation of specimens as listed in Table V did not significantly increase or decrease the shear strength. In all cases, the mode of failure indicated a brittle fracture. Figure 3 depicts a brittle fracture of the Brush SP200-C material. The ductile fracture exhibited by the PX-12 material was typical also for the Berylco XT-20, Beryllium Metals Grade 3.0, and the General Astrometals GB-2 materials.

In the case of the XT-20 material, surface removal by etching had to be increased to 0.004 inches per surface to produce consistent results and a ductile mode of fracture. Table IV shows that the shear strength increased 100 percent with a surface removal 0.004 inches per surface. Evidently, surface defects such as micro cracks and mechanical twinning resulting from grinding and machining were not completely removed by etching 0.001 inches per surface. Hence, it was concluded that a minimum surface removal of 0.004 inches per surface by etching is required for optimum shear properties.

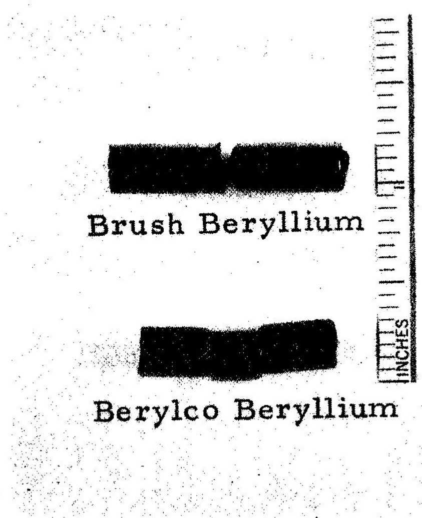

Figure 3. Photograph of Double Shear Failures of 1/4 inch Diameter Brush and Berylco Beryllium Materials.

Note the brittle failure of the Brush SP 200-C material which had a shear strength of 40,000 psi compared to the ductile failure of the Berylco material which had a shear strength of 76,000 psi.

TABLE II

BERYLLIUM MATERIALS SELECTED FOR EVALUATION

(Fastener Program for Contract NAS 8-20158)

Material Specification	Supplier	Diameter, Inches	Extrusion Reduction Ratio	Extrusion Temp., °F
PX-12	The Beryllium Corporation	0.270	105:1	1650
XT-20	The Beryllium Corporation	0.500	75:1	1650
SP-200C	The Brush Beryllium Co.	0.270	Unknown	
Grade 3.0 Powder	Beryllium Metals & Chem. Corp.	0.292	22:1	
GB-2	General Astrometals Corporation.	0.750	20:1	1920

TABLE III

CHEMICAL COMPOSITION (Wt%) OF BERYLLIUM MATERIALS
EVALUATED IN PHASE II & PHASE III
(Fastener Program for Contract NAS8-20158)
Data supplied by mills

	Beryllium Corporation		Brush Beryllium	Beryllium Metals and Chemicals	General Astrometals	Brush Beryllium
	PX-12	XT-20	SP 200-C	Grade 3.0 Powder	GB-2	Prod. Grade
Be	99.4	98.25	98.90	97.65	1.60	99.14
Be O	0.70	1.89	1.73	3.17	1235 PPM	0.86
C	0.068	0.106	0.10	0.21	853 PPM	
Fe	0.062	0.122	0.13	0.175		730 PPM
Al	0.062	0.048	0.10	0.063		290 PPM
Mg	0.075	0.039	0.01	0.016		
Si	0.037	0.063	0.03	0.055		100 PPM
Mn			0.01			105 PPM

TABLE IV
MATERIAL PROPERTIES OF BERYLCO PX-12 BERYLLIUM
(Fastener Program for Contract NAS 8-20158)

Material Specification - PX-12
Extrusion Reduction Ratio - 105:1
As Received Diameter - .270 Inches
Test Temperature - Room

1. Tensile - 0.113 inch tensile test specimen
   Etched [(a)] 0.001 inch/surface

Test No.	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation Gage, 0.5 in., %	Reduction of Area, %
1	94,300	45,400	Spec. Fractured into Several Pcs.	
2	87,700	47,400	Spec. Fractured into Several Pcs.	
3	97,400	46,900	Fractured Outside Gage	
Tested by Berylco				
4	99,700	47,600	20.0	Not Listed
5	100,800	49,100	17.5	Not Listed

2. Double Shear - 1/4 inch Diameter

   Machined to .252 inches
   Etched [(a)] 0.001 inch/surface

Test No.	Ultimate Load, Pounds	Ultimate Stress, psi [(1)]
1	7,450	75,900
2	7,480	76,200
3	7,600	77,400

(1) Stress Calculated at Twice Nominal Diameter Area, 0.09817 square inches.

(a) 100 g chromic acid (anhydride)
77 ml phosphoric acid
10 ml concentrated sulphuric acid
50 % by volume water

TABLE V

MATERIAL PROPERTIES OF BERYLCO XT-20 BERYLLIUM
(Fastener Program for Contract NAS 8-20158)

Material Specification - XT-20
Extrusion Reduction Ratio - 75:1
As - Received Diameter -0.500 inches
Test Temperature - Room

1. Tensile - 0.252 inch tensile test specimen
   Etched (b) 0.004 inch / surface

Test No.	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation Gage 1.0 in., %	Reduction of Area, %
1	90,400	41,700	8.0	5.5
2	96,800	48,100	7.0	5.4
Tested by Berylco				
3	96,500	46,100	17.0	Not listed

2. Double Shear - 1/4 inch diameter
   a. Etched 0.001 inches/surface

Test No.	Ultimate Load, pounds	Ultimate Stress, psi (1)
1	7470	76,100
2	3480	35,400
3	3920	39,900
4	4900	49,900
5	4300	43,800
6	5400	55,000
b. Etched 0.004/surface		
7	7360	75,000
8	7360	75,000

(1) Stress Calculated at Twice Nominal Diameter Area, 0.09817 square inches

(b) 49% by volume HNO_3
 2% by volume HF
 49% by volume H_2O

TABLE VI
MATERIAL PROPERTIES OF BRUSH SP 200-C BERYLLIUM
(Fastener Program for Contract NAS 8-20158)

Material Specification - SP 200-C
Extrusion Reduction Ratio - Unknown
As Received Diameter - .270 inches
Test Temperature - Room

1. Tensile - 0.113 inches tensile test specimen

   Etched [a] 0.001 inch/surface

Test No.	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation Gage, 0.5 in., %	Reduction of Area, %
1	90,600	81,300	Fractured Outside Gage Length	
2	92,100	84,200	2.0	2.0
3	88,600	80,500	2.0	2.0

2. Double Shear - 1/4 inch diameter

Test No.	Ultimate Load, pounds	Ultimate Stress, psi [1]
a. Centerless ground to .250 inches Etched [a] 0.001 inch/surface		
1	4,360	44,400
2	4,150	42,300
3	4,200	42,800
b. Universal ground to .253 inches Etched [a] 0.0015 inch/surface		
4	4,280	43,600
5	3,980	40,500
6	4,450	45,300

(a) 100 g chromic acid (anhydride)
77 ml phosphoric acid
10 ml concentrated sulphuric acid
50 % by volume water

TABLE VI (continued)

2. Double Shear - 1/4 inch diameter (continued)

Test No.	Ultimate Load, pounds	Ultimate Stress, psi (1)
c. Machined to .252 inches Etched (a) 0.001 inch/surface		
7	3,730	38,000
8	4,070	41,500
9	3,710	37,800
d. Centerless ground to 0.254 inches Etched (a) 0.0025 inch/surface		
10	4,070	41,500
11	3,920	39,900
12	4,120	42,000
e. Universal ground to 0.258 inches Etched (a) 0.004 inch/surface		
13	3,860	39,300
14	4,200	42,800
15	4,150	42,300
f. Universal ground to 0.262 inches Etched (a) 0.006 inch/surface		
16	3,800	38,700
17	3,700	38,300
18	3,990	40,600

(1) Stress calculated at Twice Nominal Diameter Area, 0.09817 square inches

TABLE VII

MATERIAL PROPERTIES OF BERYLLIUM METALS & CHEMICAL GRADE 3.0 BERYLLIUM
(Fastener Program for Contract NAS8-20158)

Material Specification Grade 3.0
Extrusion Reduction Ratio - 22:1
As Received Diameter - .287/.292 inches
Test Temperature - Room

1. Tensile - 0.113 inch tensile test specimens
   Etched (a) 0.001 inch/surface

Test No.	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation, Gage, 0.5 in., %	Reduction of Area, %
1	107,000	61,000	Spec. Fractured into Several Pcs.	
2	100,000	61,700	6.0	3.5
3	99,400	61,200	Fractured Outside Gage	

2. Double Shear - 1/4 inch diameter
   Machined to .252 inches
   Etched (a) -0.001 inch/surface

Test No.	Ultimate Load, pounds	Ultimate Stress, psi (1)
1	8,750	89,100
2	8,600	87,600
3	8,620	87,800

(1) Stress calculated at Twice Nominal Diameter Area, 0.09817 square inches.

(a) 100 g chromic acid (anhydride)
77 ml phosphoric acid
10 ml concentrated sulphuric acid
50 % by volume water

TABLE VIII

MATERIAL PROPERTIES OF GENERAL ASTROMETALS GB-2 BERYLLIUM (Fastener Program for Contract NAS8-20158)

Material Specification - GB-2
Extrusion Reduction Ratio - 20:1
As Received Diameter - .750 inches
Test Temperature - Room

1. Tensile - 0.113 inch tensile test specimens
Etched (a) 0.001 inch/surface

Test No.	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation Gage, 0.5 in., %	Reduction of Area, %
1	98,400	47,900	Gage Mark Obliterated	8.5
2	81,200	54,600	Fractured Outside Gage	
3	98,000	48,000	Section Lost During Test	
Tested by General Astrometals Average of 3 Tests				
-	89,600	46,000	5.5	Not Listed

2. Double Shear - 1/4 inch diameter
Machined to 0.252 inches
Etched [a] 0.001 inch/surface

Test No.	Ultimate Load, pounds	Ultimate Stress, psi [1]
1	6,840	69,700
2	7,280	74,200
3	7,040	71,700

(1) Stress calculated at Twice Nominal Diameter Area, 0.09817 square inches.

(a) 100 g chromic acid (anhydride)
77 ml phosphoric acid
10 ml concentrated sulphuric acid
50 % by volume water

TABLE IX

MATERIAL AND BOLT PROPERTIES OF BRUSH
FORGEABLE BERYLLIUM (PRODUCTION GRADE)

1. TENSILE

A. MATERIAL - 0.113 tensile test specimen
Pulled at 0.005 inch/inch/minute to failure

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation Gage, 0.5 in., %	Reduction of Area %
1	Room	107,100	67,300	Fractured Outside Gage	
2	Room	118,900	63,300	10	9.0
3	Room	109,700	58,700	10	5.4
4	800	42,800	34,600	34.0	57.5
5	800	43,300	39,200	48.0	56.3

TABLE IX (continued)

MATERIAL AND BOLT PROPERTIES OF BRUSH FORGEABLE BERYLLIUM (PRODUCTION GRADE)

1. TENSILE

B. BOLT PROPERTIES - 1/4-28 Hex Head Bolt

Test No.	Test Temperature, °F	Ultimate Load, Pounds	Ultimate Stress, psi (1)	Proportional Limit Yield Strength Pounds	Proportional Limit Yield Strength psi (1)
1	Room	3350	92,200	2570	70,700
2	Room	3135	86,200	2415	66,400
3	Room	2700	74,400	2265	62,300
4	800	2275	62,600		
5	800	2010	55,300		

2. DOUBLE SHEAR - 5/16 inch diameter

Test No.	Test Temperature °F	Ultimate Load, Pounds	Ultimate Stress psi (2)
1	Room	11,200	73,100
2	Room	13,300	86,800

(1) Stress claculated at the tensile stress area of 0.03637 square inches
(2) Stress calculated at twice nominal diameter area, 0.1530 square inches

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SECTION V

DEVELOPMENT OF BERYLLIUM FASTENERS

Development of beryllium fasteners was conducted concurrent to the manufacturing studies as the parts manufactured were only those found desirable from a design standpoint. The contract called for the development of both a semi-blind and a blind fastener.

The semi-blind or prestressed fastener was to have a bolt which was recessed on the threaded end for holding or driving purposes. The nut was to be a collar type nut which was grooved to permit the wrenched element to shear off at a predetermined torque. The bolt for this type of fastener assembly has been made in the past from alloy steel and titanium but never from beryllium. Therefore, the development of a beryllium prestressed fastener system was required to establish fastener configuration, manufacturing procedures and a test program.

The design of the blind fastener was to be such that it could be inserted and driven from one side of the work. The head or collar on the blind side could be beryllium or some other material suitable for the application. Although blind fasteners have been fabricated from alloy steel and aluminum, a system which would include beryllium components was never before considered. Hence, a beryllium blind fastener would be a complete innovation and would require a comprehensive development program to establish fastener configuration and manufacturing procedures.

A. Prestressed Fastener System

The bolt for the prestressed fastener assembly of the type stipulated in the contract is presently fabricated from alloy steel and titanium. It is more commonly referred to as a point drive bolt. Aluminum twist-off nuts are customarily used as the companion nut. The selected configurations for the point-drive bolt were patterned after the titanium system and are shown in Figures 4, 5 & 6.

Preliminary investigations for determining optimum dimensions for the hexagon recess were conducted with 1/4-28 studs. A hexagon recess conforming to standard dimension used for steel and titanium point-drive bolts was initially investigated. Across flats and depth dimensions were 0.094 inches and 0.156 inches respectively. Torque-out values of this design were 25 inch-pounds with failure occurring at the bottom of the hexagon recess.

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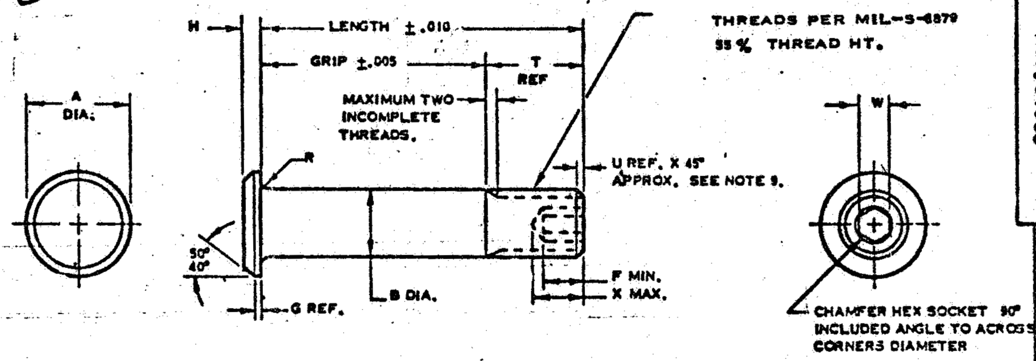
SHEET 1 OF 2

PD 300.61085



REVISION (2) REVISED AND REDRAWN 12-16-64 (3) 3-27-65 (4) 7-13-66

BASIC PART NO.	THREAD MOD.	A DIA.	B DIA.		F MIN.	G REF.	H	R RAD.	T REF.	U REF.	W	X MAX.	Y	Z
PDP 16-6	.190-32 UNF-3A	.315 .295	.1835 .1825		.125	.060	.110 .100	.025 .015	.355	.040	.0645 .0635	.156	.0045	.0040
PDP 16-8	.250-28 UNF-3A	.412 .387	.2435 .2435		.156	.070	.138 .128	.025 .015	.425	.040	.0801 .0781	.187	.0045	.0030
PDP 16-10	.312-24 UNF-3A	.505 .475	.3120 .3110		.187	.080	.156 .146	.030 .020	.530	.050	.0962 .0937	.250	.0045	.0030

NOTES.

1. MATERIAL BERYLLIUM
2. HEAT TREAT
3. FINISH ETCHED TO FINISH DIMENSIONS
4. CONCENTRICITY. "A" AND "B" DIAMETERS WITHIN .010 T.I.R., HEXAGON SOCKET AND THREAD P.D. WITHIN .010 T.I.R. THREAD P.D. AND "B" DIAMETER WITHIN "Y" VALUES T.I.R.
5. SHANK MUST BE STRAIGHT WITHIN "Z" VALUES T.I.R. PER INCH OF BOLT LENGTH.
6. PART NUMBER. FIRST DASH NUMBER DESIGNATES DIAMETER IN 1/32NDS, SECOND DASH NUMBER DESIGNATES GRIP IN 1/32NDS.
   EXAMPLE. PDP 16-8-16 - .250-28 PROTRUDING HEAD BOLT, .500 GRIP, .925 LONG.
7. SURFACE ROUGHNESS. (RHR MAXIMUM PER ASA B46.1) HEAD TO SHANK FILLET, THREAD ROOT, THREAD SIDES AND THREAD RUNOUT 16, SHANK AND BEARING SURFACE OF HEAD 40, OTHER SURFACES 125.
8. REFERENCE DIMENSIONS ARE FOR DESIGN PURPOSES ONLY AND ARE NOT AN INSPECTION REQUIRMENT.
9. CHAMFER "U" PLUS INCOMPLETE THREADS NOT TO EXCEED TWO PITCHES.
10. GAGING OF HEXAGON SOCKET PER ASA B 18.3 1961 APPENDIX 1, EXCEPT ALL "E" (NOT GO GAGE WIDTH) DIMENSIONS TO BE INCREASED .001.

P.F. Div. STANDARD

TOLERANCES ± .010 AND ± 2° UNLESS OTHERWISE NOTED

STANDARDS AND SPECIFICATIONS	TITLE BOLT, SHEAR, POINT DRIVE - PROTRUDING HEAD BERYLLIUM MATERIAL -65,000 PSI MINIMUM SHEAR	PART NUMBER PDP 16
CUSTODIAN JENKINTOWN, PENNA.		

Figure 4.

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SHEET 2 OF 2

DRAWING NUMBER *PD 300.61085

REVISION (2) REVISED AND REDRAWN 12/16/64 (3) 3-27-65 (4) 7-13-66

SECOND DASH NO.	GRIP ±.005	GRIP RANGE (FOR DESIGN) MIN.	MAX.	LENGTH ±.010 -5 .164 DIA	-6 .190 DIA	-8 .250 DIA	-10 .312 DIA	-12 .375 DIA	-14 .437 DIA	-16 .500 DIA
4	.125	.031	.125	.467	.480	.550	.655	.700	.790	.840
7	.219	.126	.219	.561	.574	.644	.749	.794	.884	.934
10	.312	.220	.312	.654	.667	.737	.842	.887	.977	1.027
13	.406	.313	.406	.748	.761	.831	.936	.981	1.071	1.121
16	.500	.407	.500	.842	.855	.925	1.030	1.075	1.165	1.215
19	.594	.501	.594	.936	.949	1.019	1.124	1.169	1.259	1.309
22	.688	.594	.688	1.030	1.043	1.113	1.218	1.263	1.353	1.403
25	.781	.689	.781	1.123	1.136	1.206	1.311	1.356	1.446	1.496
28	.875	.782	.875	1.217	1.230	1.300	1.405	1.450	1.540	1.590
31	.968	.875	.968	1.310	1.323	1.393	1.498	1.543	1.633	1.683
34	1.062	.969	1.062	1.404	1.417	1.487	1.592	1.637	1.727	1.777
37	1.156	1.063	1.156	1.498	1.511	1.581	1.686	1.731	1.821	1.871
40	1.250	1.157	1.250	1.592	1.605	1.675	1.780	1.825	1.915	1.965
43	1.344	1.251	1.344	1.686	1.699	1.769	1.874	1.919	2.009	2.059
46	1.438	1.345	1.438	1.780	1.793	1.863	1.968	2.013	2.103	2.153
49	1.531	1.439	1.531	1.873	1.886	1.956	2.061	2.106	2.196	2.246
52	1.625	1.532	1.625	1.967	1.980	2.050	2.155	2.200	2.290	2.340
55	1.719	1.626	1.719	2.061	2.074	2.144	2.249	2.294	2.384	2.434
58	1.812	1.720	1.812	2.154	2.167	2.237	2.342	2.387	2.477	2.527
61	1.906	1.813	1.906	2.148	2.261	2.331	2.436	2.481	2.571	2.621
64	2.000	1.907	2.000	2.342	2.355	2.425	2.530	2.575	2.665	2.715
67	2.094	2.001	2.094	2.436	2.449	2.519	2.624	2.669	2.759	2.809
70	2.188	2.095	2.188	2.530	2.543	2.613	2.718	2.763	2.853	2.903
73	2.281	2.189	2.281	2.623	2.636	2.706	2.811	2.856	2.956	2.996
76	2.375	2.282	2.375	2.717	2.730	2.800	2.905	2.950	3.040	3.090
79	2.469	2.376	2.469	2.811	2.824	2.894	2.999	3.044	3.134	3.184
82	2.562	2.470	2.562	2.904	2.917	2.987	3.092	3.137	3.227	3.277
85	2.656	2.563	2.656	2.998	3.011	3.081	3.186	3.231	3.321	3.371
88	2.750	2.657	2.750	3.092	3.105	3.175	3.280	3.325	3.415	3.465
91	2.844	2.751	2.844	3.186	3.199	3.269	3.374	3.419	3.509	3.559
94	2.938	2.845	2.938	3.280	3.293	3.363	3.468	3.513	3.603	3.653
97	3.031	2.939	3.031	3.373	3.386	3.456	3.561	3.606	3.696	3.376
100	3.125	3.032	3.125	3.467	3.480	3.550	3.655	3.700	3.790	3.840
103	3.219	3.126	3.219	3.561	3.574	3.644	3.749	3.794	3.884	3.934
106	3.312	3.220	3.312	3.654	3.667	3.737	3.842	3.887	3.977	4.027
109	3.406	3.313	3.406	3.748	3.761	3.831	3.936	3.981	4.071	4.121
112	3.500	3.407	3.500	3.842	3.855	3.925	4.030	4.075	4.165	4.215
115	3.594	3.501	3.594	3.936	3.949	4.019	4.124	4.169	4.259	4.309
118	3.688	3.595	3.688	4.030	4.043	4.113	4.218	4.263	4.353	4.403
121	3.781	3.689	3.781	4.123	4.136	4.206	4.311	4.356	4.446	4.496
124	3.875	3.782	3.875	4.217	4.230	4.300	4.405	4.450	4.540	4.590
127	3.969	3.876	3.969	4.311	4.324	4.394	4.499	4.544	4.634	4.684
130	4.062	3.970	4.062	4.404	4.417	4.487	4.592	4.637	4.727	4.777

INTERMEDIATE GRIP LENGTHS MAY BE OBTAINED BY SPECIFYING INTERMEDIATE WHOLE DASH NUMBERS.

Figure 4. (continued)

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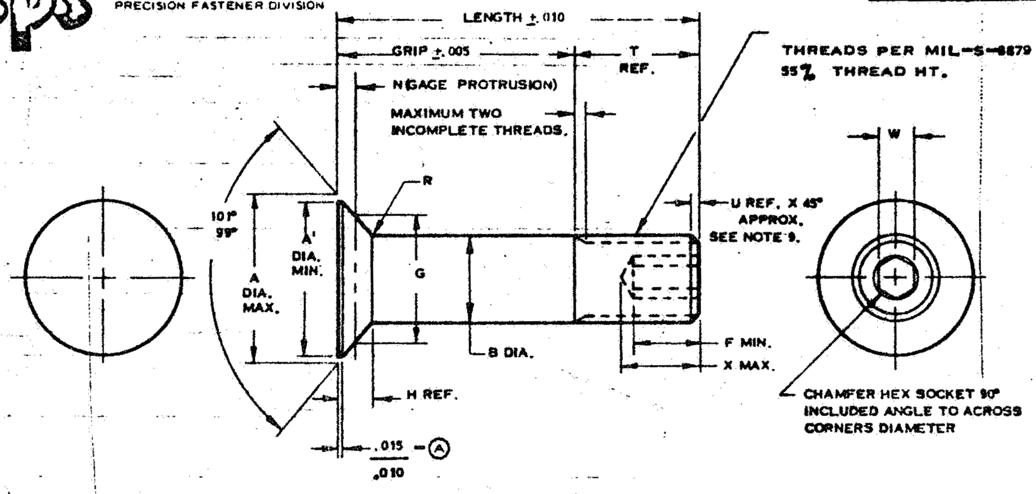
PRECISION FASTENER DIVISION

SHEET 1 OF 2

PD 300.61084

REVISION (A) 5-20-66



BASIC PART NO.	THREAD MOD.	A MAX. 1/	A' MIN. 2/	B DIA.		F MIN.	G GAGE DIA.	H REF.	N	R RAD.	T REF.	U REF.	W	X MAX.	Y	Z
PTF 16-3	.190-32 UNF-3A	.302	.257	.1895 .1890		.125	.2210 .2208	.046	.0333 .0305	.030 .020	.325	.040	.0645 .0635	.156	.0045	.0040
PTF 16-4	.250-28 UNF-3A	.395	.349	.2495 .2490		.156	.2832 .2830	.060	.0461 .0430	.030 .020	.395	.040	.0801 .0781	.187	.0045	.0030
PTF 16-5	.312-24 UNF-3A	.474	.428	.3120 .3115		.187	.3422 .3420	.067	.0544 .0513	.040 .030	.500	.050	.0962 .0937	.250	.0045	.0030

1/ TO THEORETICAL SHARP CORNER   2/ ABSOLUTE MINIMUM WITH FLAT.

NOTES.

1. MATERIAL BERYLLIUM
2. HEAT TREAT
3. FINISH PLAIN ETCHED TO FINISH DIMENSIONS
4. CONCENTRICITY. CONICAL SURFACE OF HEAD TO "B" DIAMETER WITHIN .005 T.I.R.
   THREAD P.D. AND "B" DIAMETER WITHIN "Y" VALUES T.I.R.
   HEXAGON SOCKET AND THREAD P.D. WITHIN .010 T.I.R.
5. SHANK MUST BE STRAIGHT WITHIN "Z" VALUES T.I.R. PER INCH OF BOLT LENGTH.
6. PART NUMBER. FIRST DASH NUMBER DESIGNATES DIAMETER.
   SECOND DASH NUMBER DESIGNATES GRIP LENGTH IN 1/16 THS.
   EXAMPLE. PTF 16-5-10 = .312-24 DIAMETER BOLT, .625 GRIP, 1.125 LONG.
7. SURFACE ROUGHNESS (RHR MAXIMUM PER ASA B46.1) HEAD TO SHANK FILLET, THREAD ROOT, THREAD SIDES, AND THREAD RUNOUT 16, SHANK AND HEAD BEARING SURFACE 40, OTHER SURFACES 125.
8. REFERENCE DIMENSIONS ARE FOR DESIGN PURPOSES AND ARE NOT AN INSPECTION REQUIREMENT.
9. CHAMFER "U" PLUS INCOMPLETE THREADS NOT TO EXCEED TWO PITCHES.
10. GAGING OF HEXAGON SOCKET PER ASA B18.3 1961 APPENDIX 1, EXCEPT ALL "E" (NOT GO GAGE WIDTH) DIMENSIONS TO BE INCREASED .001.

TOLERANCES: .010 AND ±2° UNLESS OTHERWISE NOTED

STANDARDS AND SPECIFICATIONS	TITLE BOLT, SHEAR, POINT DRIVE - 100° FLUSH HEAD BERYLLIUM MATERIAL - 65,000 PSI MINIMUM SHEAR 1/16 GRIP VARIATION APPLICATIONS	PART NUMBER PTF 16
CUSTODIAN. JENKINTOWN, PA.		

Figure 5.

STANDARD PRESSED STEEL CO.
PRECISION FASTENER DIVISION

SHEET 2 OF 2

DRAWING NUMBER PD 300.61084

REVISION 1 5-20-66

2ND DASH NO.	GRIP ±.005	GRIP RANGE (FOR DESIGN) MIN.	GRIP RANGE (FOR DESIGN) MAX.	LENGTH ±.010 .164 DIA	.190 DIA	.250 DIA	.312 DIA	.375 DIA	.437 DIA	.500 DIA
2	.125	.063	.125	.437	.450	.520	.625	.670	.760	.810
3	.188	.126	.188	.500	.513	.583	.688	.733	.823	.873
4	.250	.189	.250	.562	.575	.645	.750	.795	.885	.935
5	.312	.251	.312	.624	.637	.707	.812	.857	.947	.997
6	.375	.313	.375	.687	.700	.770	.875	.920	1.010	1.060
7	.438	.376	.438	.750	.763	.833	.938	.983	1.073	1.123
8	.500	.439	.500	.812	.825	.895	1.000	1.045	1.135	1.185
9	.562	.501	.562	.874	.887	.957	1.062-	1.107	1.197	1.247
10	.625	.563	.625	.937	.950	1.020	1.125	1.170	1.260	1.310
11	.688	.626	.888	1.000	1.013	1.083	1.188	1.233	1.323	1.373
12	.750	.689	.750	1.062	1.075	1.145	1.250	1.295	1.385	1.435
13	.812	.751	.812	1.124	1.137	1.207	1.312	1.357	1.447	1.497
14	.875	.813	.875	1.187	1.200	1.270	1.375	1.420	1.510	1.560
15	.938	.876	.938	1.250	1.263	1.333	1.438	1.483	1.573	1.623
16	1.000	.939	1.000	1.312	1.325	1.395	1.500	1.545	1.635	1.685
17	1.062	1.001	1.062	1.374	1.387	1.457	1.562	1.607	1.697	1.747
18	1.125	1.063	1.125	1.437	1.450	1.520	1.625	1.670	1.760	1.810
19	1.188	1.126	1.188	1.500	1.513	1.583	1.688	1.733	1.823	1.873
20	1.250	1.189	1.250	1.562	1.575	1.645	1.750	1.795	1.885	1.935
21	1.312	1.251	1.312	1.624	1.637	1.707	1.812	1.857	1.947	1.997
22	1.375	1.313	1.375	1.687	1.700	1.770	1.875	1.920	2.010	2.060
23	1.438	1.376	1.438	1.750	1.763	1.833	1.938	1.983	2.073	2.123
24	1.500	1.439	1.500	1.812	1.825	1.895	2.000	2.045	2.135	2.185
25	1.562	1.501	1.562	1.874	1.887	1.957	2.062	2.107	2.197	2.247
26	1.625	1.563	1.625	1.937	1.950	2.020	2.125	2.170	2.260	2.310
27	1.688	1.625	1.688	2.000	2.013	2.083	2.183	2.233	2.323	2.373
28	1.750	1.689	1.750	2.062	2.075	2.145	2.250	2.295	2.385	2.435
29	1.812	1.751	1.812	2.124	2.137	2.207	2.312	2.357	2.447	2.497
30	1.875	1.813	1.875	2.187	2.200	2.270	2.375	2.420	2.510	2.560
31	1.938	1.876	1.938	2.250	2.263	2.333	2.438	2.483	2.573	2.623
32	2.000	1.939	2.000	2.312	2.325	2.395	2.500	2.545	2.635	2.685
33	2.062	2.001	2.062	2.374	2.387	2.457	2.562	2.607	2.697	2.747
34	2.125	2.063	2.125	2.437	2.450	2.520	2.625	2.670	2.760	2.810
35	2.188	2.126	2.188	2.500	2.513	2.583	2.688	2.733	2.823	2.873
36	2.250	2.189	2.250	2.562	2.575	2.645	2.750	2.795	2.885	2.935
37	2.312	2.251	2.312	2.624	2.637	2.707	2.812	2.857	2.947	2.997
38	2.375	2.313	2.375	2.687	2.700	2.770	2.875	2.920	3.010	3.060
39	2.438	2.376	2.438	2.750	2.763	2.833	2.938	2.983	3.073	3.123
40	2.500	2.439	2.500	2.812	2.825	2.895	3.000	3.045	3.135	3.185
41	2.562	2.501	2.562	2.874	2.887	2.957	3.062	3.107	3.197	3.247
42	2.625	2.563	2.625	2.937	2.950	3.020	3.125	3.170	3.260	3.310
43	2.688	2.626	2.688	3.000	3.013	3.083	3.188	3.233	3.323	3.373
44	2.750	2.689	2.750	3.062	3.075	3.145	3.250	3.295	3.385	3.435
45	2.812	2.751	2.812	3.124	3.137	3.207	3.312	3.357	3.447	3.497
46	3.875	2.813	2.875	3.187	3.200	3.270	3.375	3.420	3.510	3.560
47	2.938	2.876	2.938	3.250	3.263	3.333	3.438	3.483	3.573	3.623
48	3.000	2.939	3.000	3.312	3.325	3.395	3.500	3.545	3.635	3.685
49	3.062	3.001	3.062	3.374	3.387	3.457	3.562	3.607	3.697	3.747
50	3.125	3.063	3.125	3.437	3.450	3.520	3.625	3.670	3.760	3.810
51	3.188	3.126	3.188	3.500	3.513	3.583	3.688	3.733	3.823	3.873
52	3.250	3.189	3.250	3.562	3.575	3.645	3.750	3.795	3.885	3.935
53	3.312	3.251	3.312	3.624	3.637	3.707	3.812	3.857	3.947	3.997
54	3.375	3.313	3.375	3.687	3.700	3.770	3.875	3.920	4.010	4.060
55	3.438	3.376	3.438	3.750	3.763	3.833	3.938	3.983	4.073	4.123
56	3.500	3.439	3.500	3.812	3.825	3.895	4.000	4.045	4.135	4.185
57	3.562	3.501	3.562	3.874	3.887	3.957	4.062	4.107	4.197	4.247
58	3.625	3.563	3.625	3.937	3.950	4.020	4.125	4.170	4.260	4.310
59	3.688	3.626	3.688	4.000	4.013	4.083	4.188	4.233	4.323	4.373
60	3.750	3.689	3.750	4.062	4.075	4.145	4.250	4.295	4.385	4.435
61	3.812	3.751	3.812	4.124	4.137	4.207	4.312	4.357	4.447	4.497
62	3.875	3.813	3.875	4.187	4.200	4.270	4.375	4.420	4.510	4.560
63	3.938	3.876	3.938	4.250	4.263	4.333	4.438	4.483	4.573	4.623
64	4.000	3.939	4.000	4.312	4.325	4.395	4.500	4.545	4.635	4.685

Figure 5. (continued)

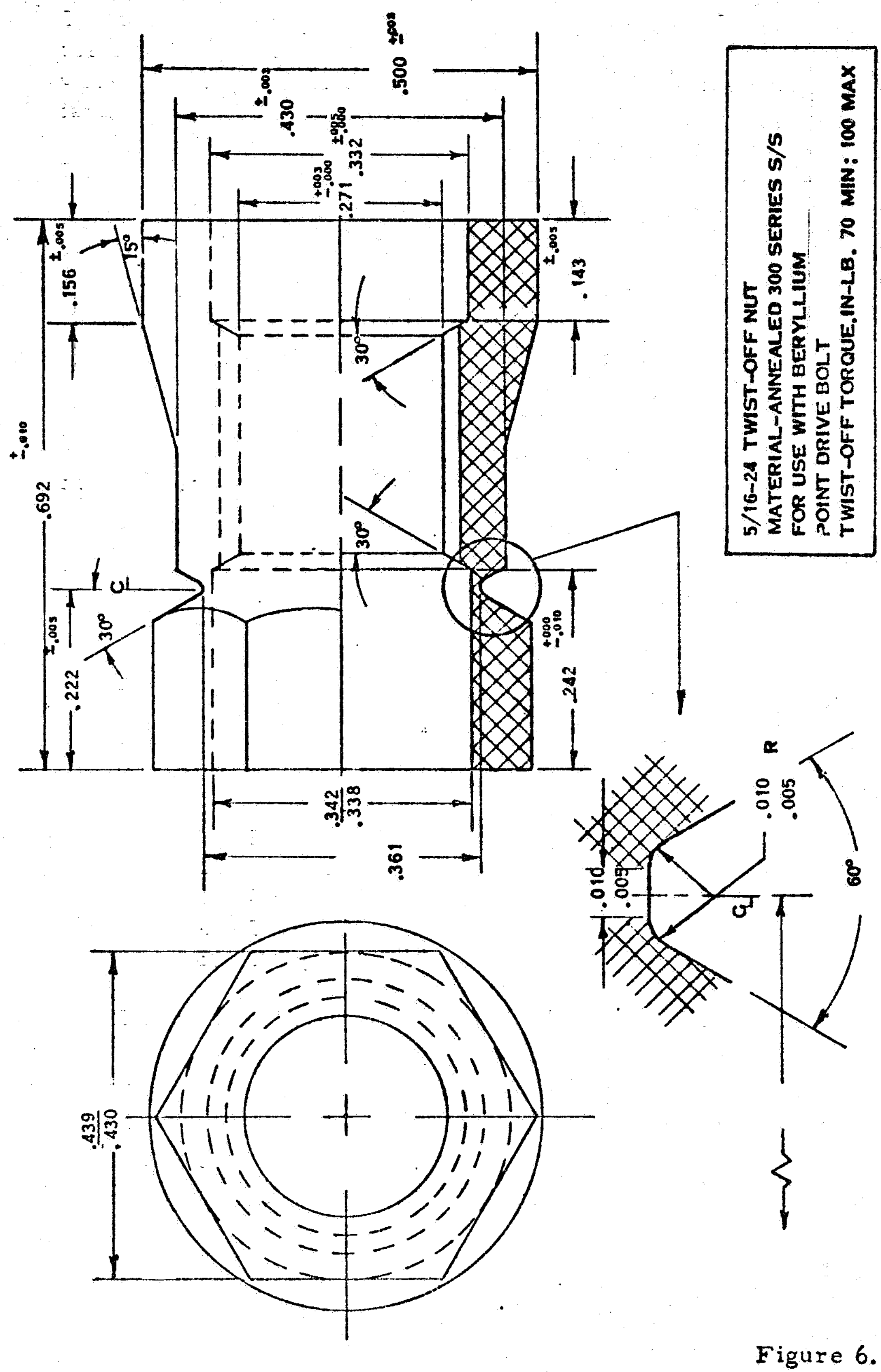

5/16-24 TWIST-OFF NUT
MATERIAL-ANNEALED 300 SERIES S/S
FOR USE WITH BERYLLIUM
POINT DRIVE BOLT
TWIST-OFF TORQUE, IN-LB. 70 MIN; 100 MAX

Figure 6.

A. Prestressed Fastener System (continued)

The across flats dimension was decreased to 0.078 inches and the depth to 0.125 inches. Torque-out values for this design were on the order of 30 inch-pounds which produced wrench failures.

For the 5/16-24 thread diameter, hexagon recess dimensions were 0.094 inches across flats at a depth of 0.156 inches. Torque-out tests resulted in wrench failures at approximately 50 inch-pounds.

It was therefore concluded that optimum dimensions for the hexagon recess for the 1/4-28 and 5/16-24 prestressed fasteners would be those below:

Thread size	Drill Hole Depth, inches (Max.)	Across Flats, inches	Depth of Recess inches (Min.)
1/4-28	0.156	0.0801/0.0781	0.125
5/16-24	0.205	0.0962/0.0937	0.156

1. Testing

The two fastener configurations were tested with the goal of determining which tests were significant from both a qualification and inspection standpoint. Tests investigated were:

1. Fastener Preload
2. Ultimate Tensile Strength
3. Double Shear of Bolt Shank
4. Tension-Tension Fatigue
5. Torque-Tension

The testing program was also conducted to determine if the selected fastener configurations fabricated from XT-20 material would meet the minimum requirements of:

Bolt Ultimate Tensile - 75,000 psi
Shear Strength - 65,000 psi
Bolt Endurance Limit - 10^6 cycles at 45,000 psi

A. Prestressed Fastener System (continued)

2. Results

The test results tabulated in Tables IX and X show that beryllium point-drive bolts with forward extruded heads and fabricated from Berylco XT-20 material would meet the minimum requirements previously stipulated.

The tensile and fatigue results for the 100° flush head bolts listed in Table IX indicated that the head dimensions could be changed to realize higher strengths. This would involve increasing the head band height from 0.015 inches to 0.062 inches. However, the Project Monitor requested that the low band height be employed to conform with standards for similar types of titanium fasteners.

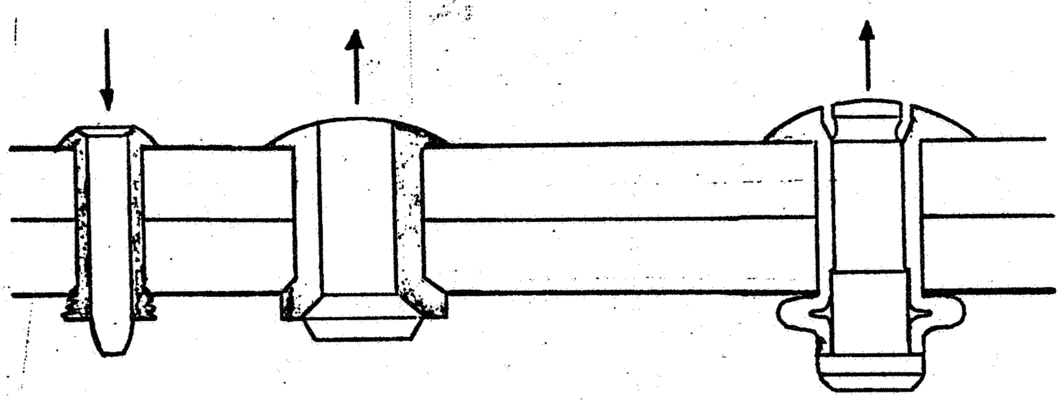
B. Blind Fastener System

1. Introduction and Goals

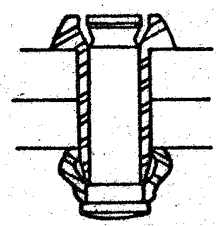
Blind fasteners are those that are installed and tightened from one side only. They have a place in structural design because frequently a component cannot be assembled with access to both sides. These type bolts (or rivets) have been available for many years in several designs and quality levels. The characteristics common to all blind fasteners are they are multi-piece and at least one member plastically deforms in the transverse direction (See Figure 7) (Ref. 3&4).

The first and most logical approach to developing a beryllium blind fastener was to substitute beryllium material in an existing design. The need for transverse plastic deformation immediately meant that at least one part must be non-beryllium. The initial approach was to make this one part of aluminum; however, the scope of work of the contract was changed to include an 800°F requirement, so that work on aluminum components was abandoned in favor of including a high temperature steel.

In surveying the existing designs it was further noticed that many configurations featured a breakneck (Figure 8).



Representative Blind Fasteners using expanded sleeves as fastening devices



Huck Type Tau Blind Bolt. This Fastener has a break-off element on the core bolt to establish maximum seating torque values.

<u>Figure 7.</u> Typical Multi-Piece Blind Fasteners

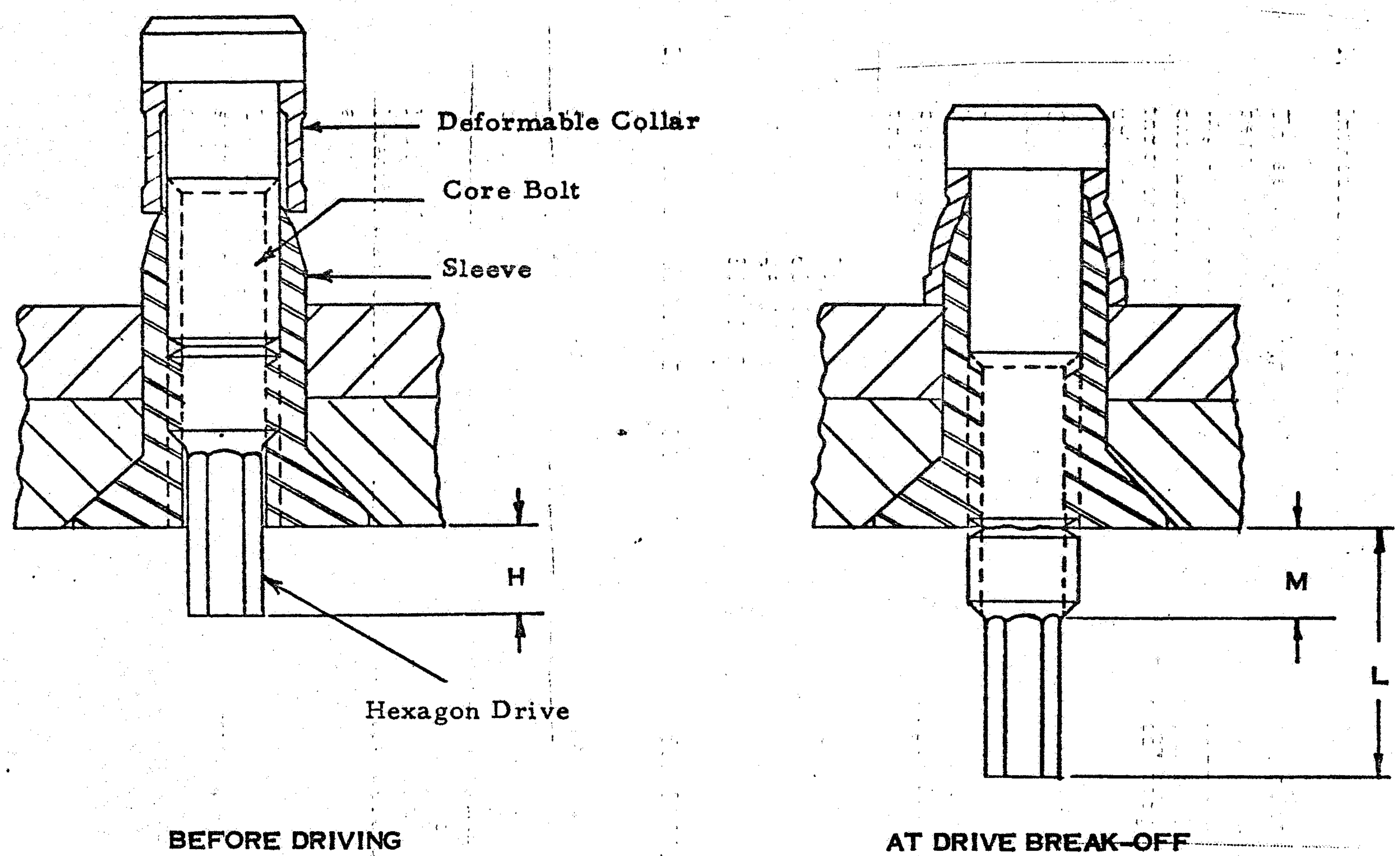


Figure 8. Schematic Sketch of Blind Fastener System Requiring Break-Off for Installation

B. Blind Fastener System (continued)

1. **Introduction and Goals (continued)**

These were also immediately eliminated from consideration because of the health hazard problem associated with breaking beryllium in a production area, the unpredicatable failure characteristics of brittle beryllium, and the high cost of throwing away the breakoff material. Typical target configuration was that shown in Figure 9.

Other considerations in the use of beryllium blind fastener components were brittleness of the material, galling tendency, low transverse and torsional strength, and machining limitations. All these factors had to be balanced before beginning to design a blind fastener with target fastener properties of:

75,000 psi Ultimate Tensile Strength
65,000 psi Shear Strength
45,000 psi Endurance Stress
800°F Capability

2. Development of a Beryllium Blind Fastener for 800°F Application

Since the scope of work was changed to include a maximum utilization temperature of 800°F, this necessitated the use of heat resistant alloys for both the sleeve and collar. For maximum weight reduction, Berylco XT-20 beryllium was selected for the sleeve and stainless steel for the collar. Much of the design development for room temperature application was carried over into the elevated temperature application.

Four different types of blind fastener system were evaluated. The inter-relationship between the components for a specific system required the investigation of many variables. These variables included the design of the core bolt, sleeve and collar, collar material, lubricants, driving mechanisms and the establishment of swaging and seating loads.

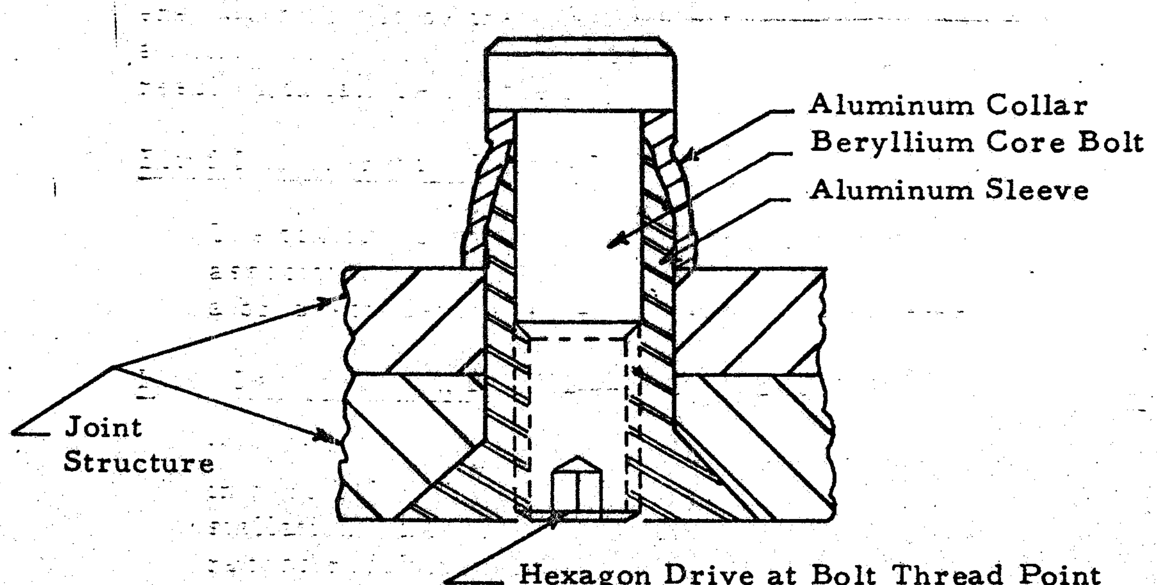


Figure 9. Blind Fastener System with Hexagon Recess Driving Mechanism in Point of Core Bolt

2. **Development of a Beryllium Blind Fastener for 800°F Application (continued)**

Of the four systems evaluated, only one system was considered feasible and practical for a beryllium blind fastener application. The design consisted of a three piece assembly core bolt, sleeve, and collar-nut combination. It required a two step installation in which the collar-nut combination was swaged over a beryllium sleeve with a threaded steel mandrel. After swaging of the collar, the mandrel was disengaged and replaced with a beryllium core bolt. A schematic drawing of the installation procedure for this system is illustrated in Figure 10.

Initially, the goal of the program was to develop a blind fastener which could be installed in a single operation. However, attempts to develop the various types of this fastener system resulted in failure for the following reasons:

<u>Blind Fastener with Break-Off Driving Mechanism</u>

The toxicity problem and high cost of input material associated with beryllium would not permit the use of a break-off device for establishing seating torques.

<u>Blind Fastener with Point Drive Core Bolt</u>

Use of standard hexagon recess configurations resulted in core bolt failure at the base of the recess during installation. Decreasing the dimensions of the hexagon recess resulted in failure of the hexagon drive. The torque values required for full installation of the collars exceeded the torsional yield strength of standard hexagon wrenches.

Successful swaging was achieved when the hexagon recess was extended into the shank of the beryllium core bolt. However,tensile and shear properties were adversely affected with a significant decrease in strength.

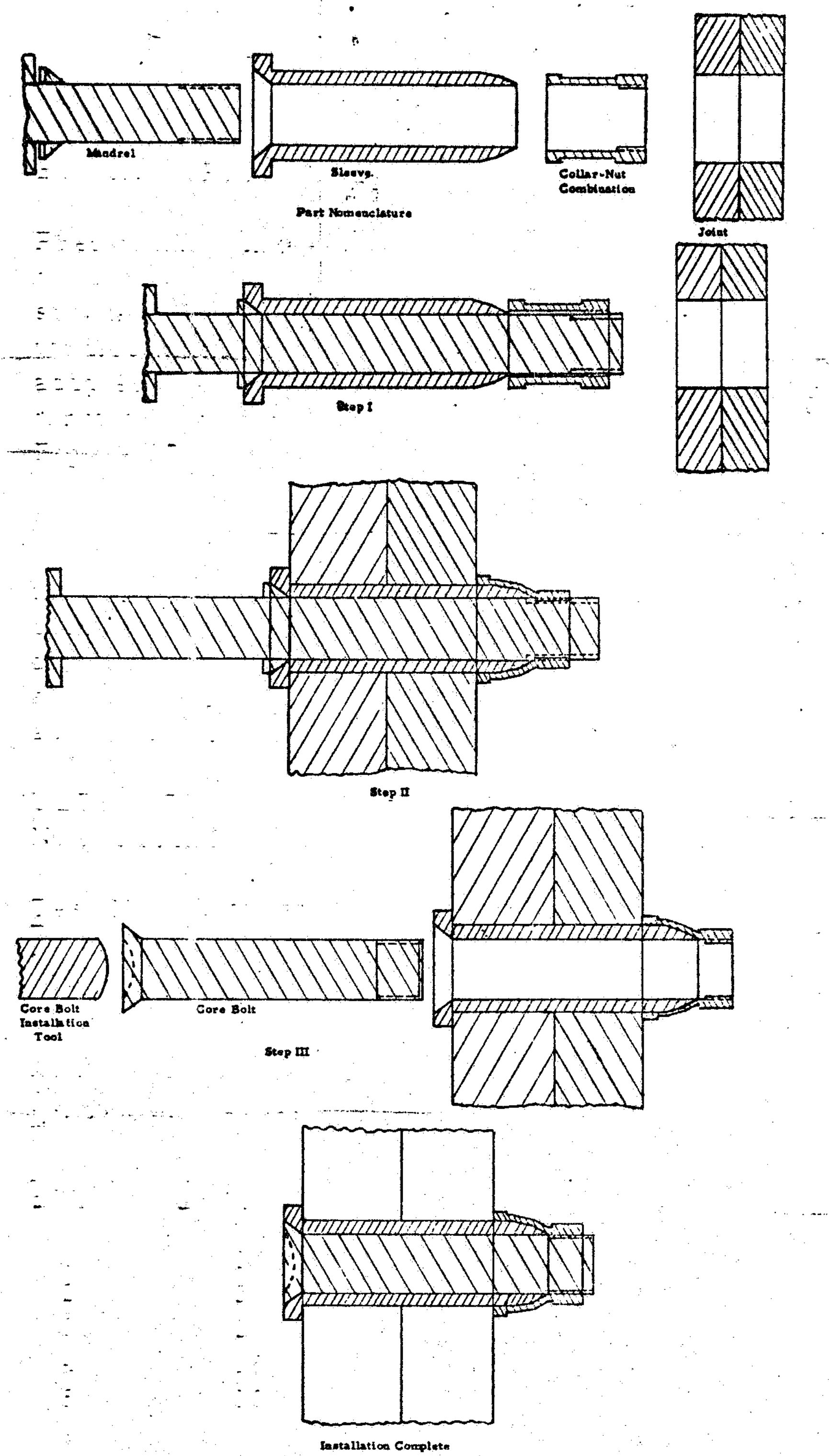


Figure 10. Installation Procedure for Beryllium Press-Swage Blind Fastener

B. 2. Development of a Beryllium Blind Fastener for 800°F Application (continued)

Blind Fastener with Permanent External Hexagon Drive

High sleeve rejection rates were associated with the use of tapped beryllium sleeves.

Blind Fastener with Expansible Sleeve

It would not be feasible to manufacture an expansible sleeve from beryllium material.

Stainless Steel Elliptical Press Nuts with Beryllium Core Bolts

High installation forces were required for this type of fastener, and therefore, would eliminate its usage with thin beryllium sheet.

a. Beryllium Press-Swage Blind Fastener

Blind fasteners employing the press-swage principle proved to be the only feasible and practical system for beryllium application. The system combines the principles of both the Davis Press Nut and the SPS commercial blind fastener. Incorporated with the design were the collar and sleeve configurations established during the investigation of the three other systems evaluated.

The design consists of a three piece assembly-core bolt, sleeve, and collar-nut combination. (Figures 11, 12, and 13. As shown in Figure 10, the collar-nut combination is swaged over the sleeve with a threaded steel mandrel. After swaging of the collar, the mandrel is disengaged and replaced with a beryllium core bolt.

B 2. Development of a Beryllium Blind Fastener for 800°F Application (continued)

a. Beryllium Press-Swage Blind Fastener (continued)

Preliminary investigations for the 5/16 diameter were conducted with the bolt, sleeve and collar-nut combination shown in Figures 14, 15, and 16. Installation was performed manually using an SPS DN 512 Press-Nut tool adapter. A composite photograph of the adapter in conjunction with a fully swaged fastener is illustrated in Figure 17.

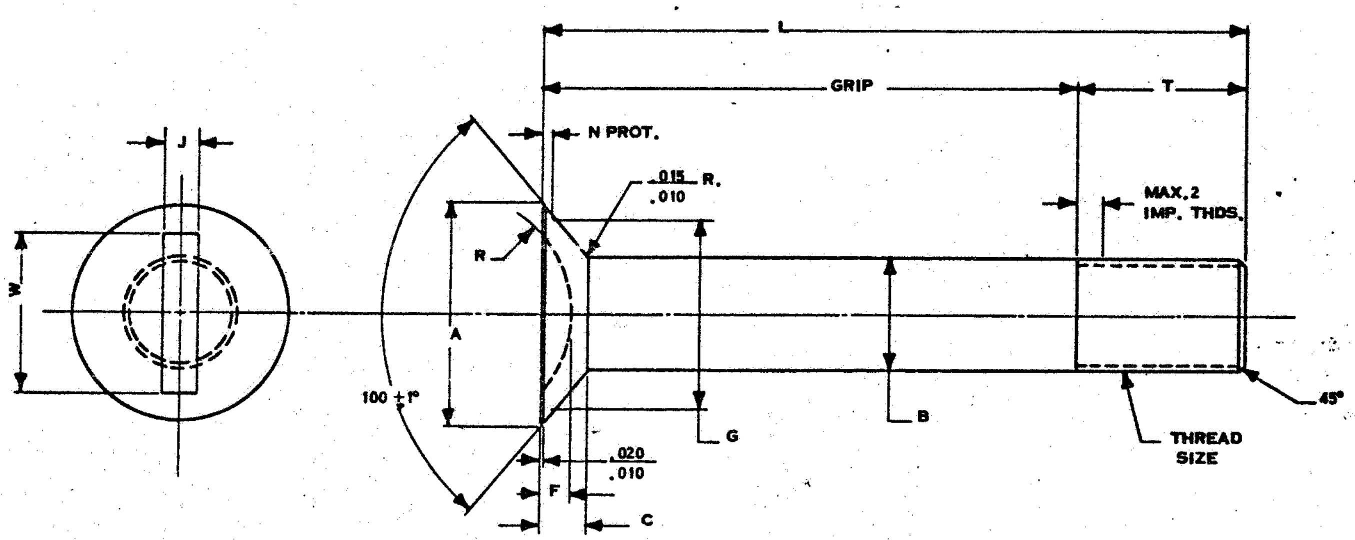
Sleeves for the investigation were fabricated with both single and double angles to determine which would develop the higher preload. Tensile strengths of the collar-nut combination and the #12-28 hexagon head core bolt were also established. The nuts were tested with stainless steel bolts and the core bolts were tested with threaded adapters. The results were:

ULTIMATE TENSILE STRENGTH OF #12-28 COLLAR-NUT COMBINATION

Test No.	Ultimate Load, lbs.	Location of Failure
1	1700	Collar Threads Stripped
2	1650	Collar Threads Stripped

ULTIMATE TENSILE STRENGTH OF #12-28 BERYLLIUM HEXAGON HEAD BOLTS

Test No.	Ultimate Load, lbs.	Location of Failure
1	2000	Thread
2	2000	Head
3	2000	Head
4	1500	Head
5	1200	Thread Runout



ASSEMBLY SIZE	A MAX.	A MIN.	B MAX.	B MIN.	C REF.	F MAX.	F MIN.	G REF.	J MAX.	J MIN.	GRIP MAX.	GRIP MIN.	L MAX.	L MIN.	N MAX.	N MIN.	R MAX.	R MIN.	T REF.	THREAD SIZE [illegible] FORM	F REF.
5/16	.450	.440	.216	.215	.091	.054	.050	.3798	.074	.070	1.200	1.180	1.575	1.555	.0300	.0248	.364	.354	.375	12-28-3A	.350
1/4	.385	.375	.190	.189	.080	.045	.043	.3143	.064	.060	.960	.940	1.335	1.315	.0302	.0250	.286	.276	.375	10-32-3A	.305
10	.275	.270	.138	.137	.068	.035	.031	.1985	.054	.050	.730	.710	1.045	1.045	.0326	.0294	.170	.160	.315	6-32-3A	.225

100° FLUSH HEAD CORE BOLT

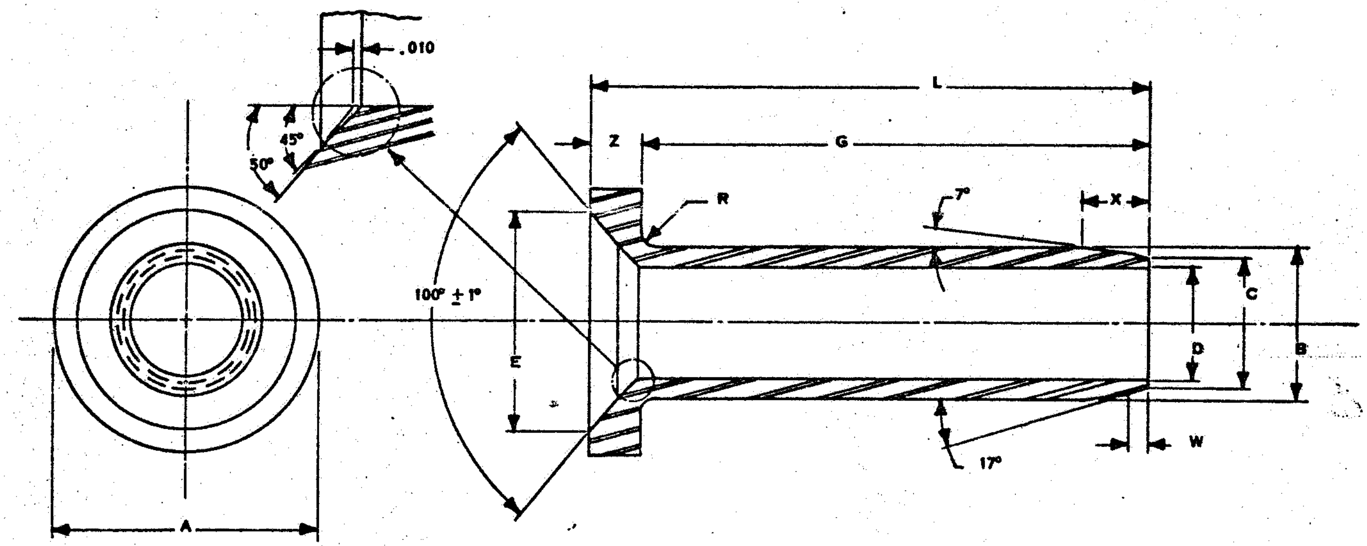
PROTRUDING HEAD BLIND FASTENER SYSTEM

TOLERANCE UNLESS SPECIFIED
FRACT.:
DEC.:
ANGLES:
SURF. FIN. ✓

LABORATORIES
STANDARD PRESSED STEEL CO., JENKINTOWN, PA.

MAT'L. BERYLLIUM | HEAT TREAT
SCALE NONE | NO. REQD | ASSY DWG. | PARTS LIST
DRAWN BY [illegible]
DATE 3-9-67 | DWG. NO.

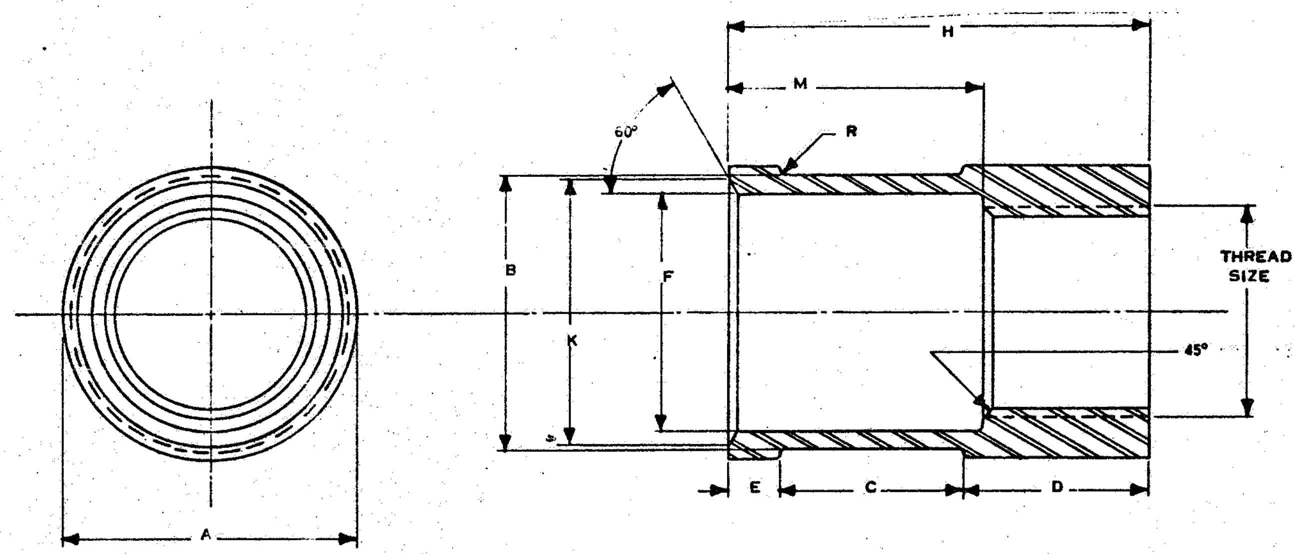
Figure 11.



SIZE	A	B MAX.	B MIN.	C	D MAX.	D MIN.	E MAX.	E MIN.	G MAX.	G MIN.	L	R MAX.	R MIN.	W REF.	X	Z REF.
5/16	.500	.311	.310	.250	.219	.218	.454	.444	1.145	1.140	1.270	.025	.015	.060	.150	.130
1/4	.435	.249	.248	.210	.193	.192	.390	.379	.925	.920	1.030	.025	.015	.040	.110	.106
10	.310	.1895	.1890	.156	.140	.139	.280	.272	.725	.720	.800	.025	.015	.030	.090	.080

SLEEVE PROTRUDING HEAD BLIND FASTENER SYSTEM	TOLERANCE UNLESS SPECIFIED FRACT.: DEC.: ANGLES: SURF. FIN. ✓	LABORATORIES STANDARD PRESSED STEEL CO., JENKINTOWN, PA., 19046 MAT'L. BERYLLIUM HEAT TREAT SCALE NO. REQD ASSY. DWG. PARTS LIST DRAWN BY LEHNEN DATE 3-9-67 DWG. NO.

Figure 12



SIZE	THREAD SIZE 55 FORM	A MAX.	A MIN.	B MAX.	B MIN.	C	D REF.	E MAX.	E MIN.	F MAX.	F MIN.	H MAX.	H MIN.	K MAX.	K MIN.	M MAX.	M MIN.	R MAX.	R MIN.
5/16	12-28-3B	.310	.308	.296	.294	.205	.175	.065	.060	.249	.246	.444	.439	.280	.268	.280	.275	.020	.015
1/4	10-32-3B	.248	.246	.243	.240	.165	.165	.060	.055	.210	.205	.394	.389	.228	.218	.245	.240	.015	.010
10	6-32-3B	.190	.188	.185	.182	.150	.100	.050	.045	.158	.156	.305	.300	.172	.166	.215	.200	.015	.010

REVISION AND DATE

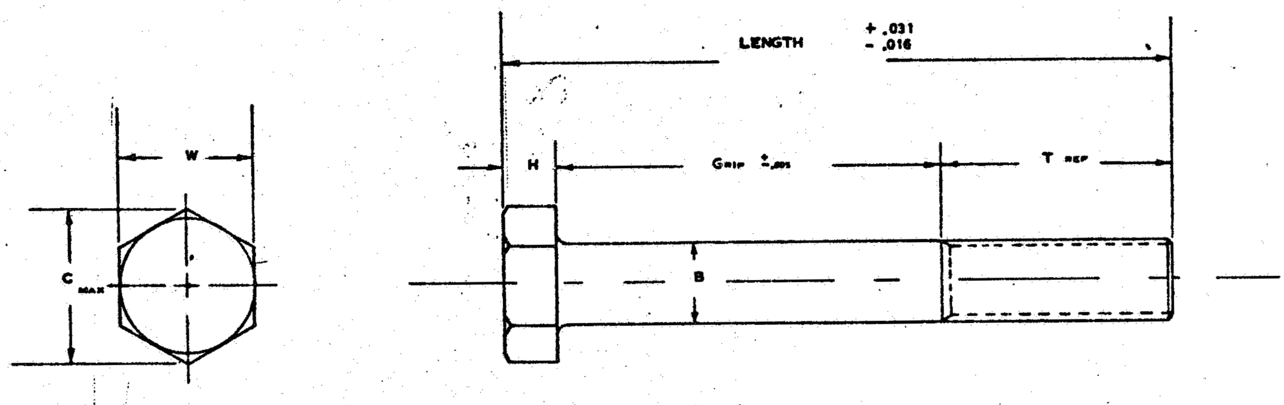
COLLAR-NUT COMBINATION
FOR
BLIND FASTENER SYSTEM

TOLERANCE UNLESS SPECIFIED
FRACT.:
DEC.:
ANGLES:
SURF. FIN ✓

SPS LABORATORIES
STANDARD PRESSED STEEL CO., JENKINTOWN, PA., 19046

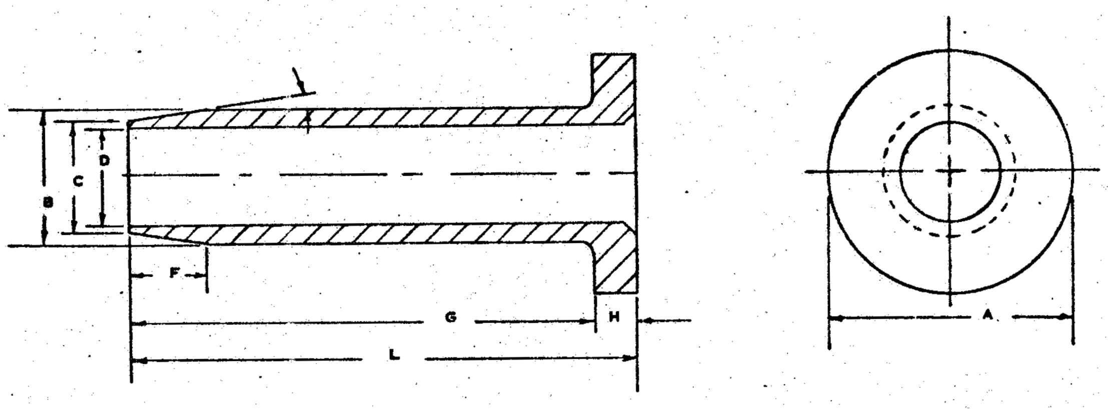
MAT'L. STAINLESS 304
HEAT TREAT ANNEAL 1700°F 10 MIN., H_2O QUENCH
SCALE NONE
NO. REQD
ASSY. DWG.
PARTS LIST
DRAWN BY LENNEN
DATE 3-9-67
DWG. NO.

Figure 13.



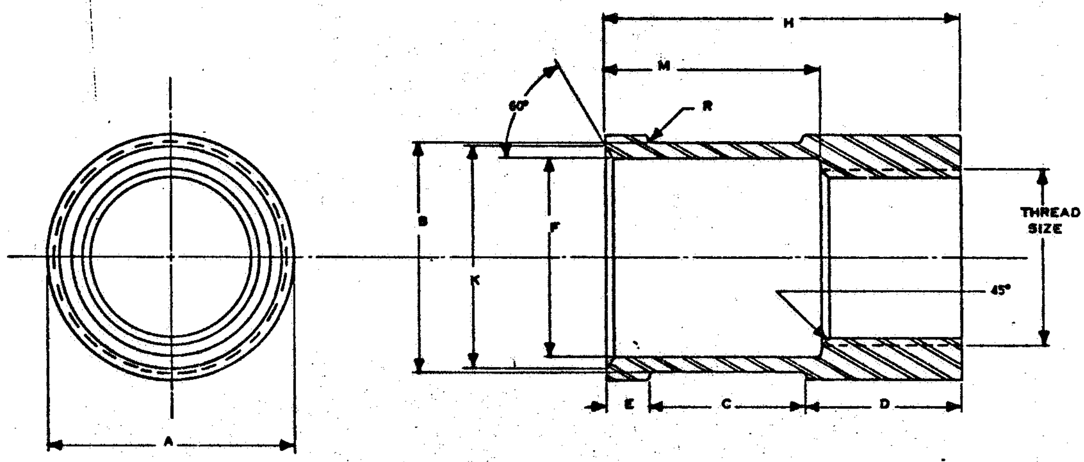
SIZE	THREAD FORM	W MAX	W MIN	C MAX	B MAX	B MIN	H MAX	H MIN	T REF MAX	T REF MIN	GRIP MAX	GRIP MIN	LENGTH
12	12-28-3A		.375		.2160	.2155	.108	.100		.214	1.250		1.467

Figure 14. Core Bolt for Protruding Head Blind Fastener System



SIZE	A MAX		B MAX	B MIN	C REF		D MAX	D MIN	F MAX	F MIN	G MAX	G MIN	H REF	L MIN	∢ ±
5/16	.500		.311	.310	.250		.219	.218	.060		1.145	1.140	.130	1.270	7°

Figure 15. Drawing of Sleeve for Protruding Head Blind Fastener



SIZE	THREAD SIZE 55 FORM	A		B		C	D	E		F		H		K		M		R	
		MAX.	MIN.	MAX.	MIN.		REF.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.
5/16	12-28-3B	.310	.308	.296	.294	.205	.175	.065	.060	.249	.246	.444	.439	.280	.268	.280	.275	.020	.015

Figure 16. Collar-Nut Combination for Blind Fastener System

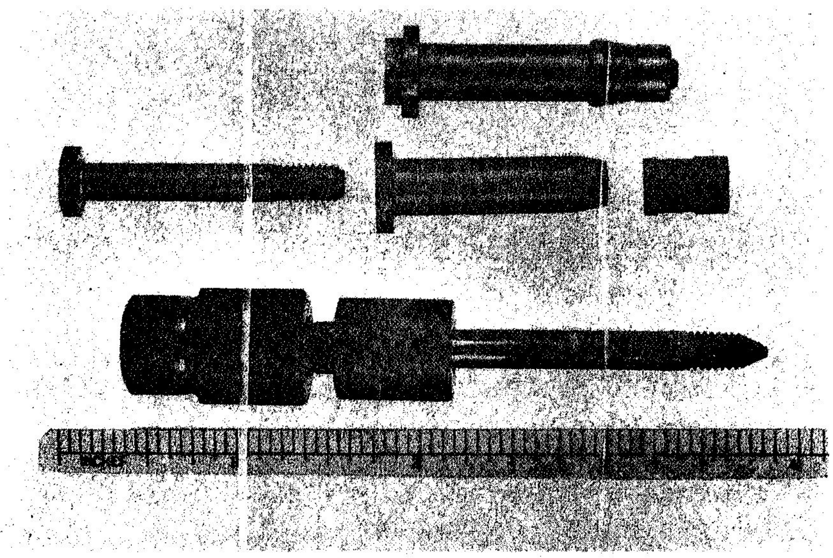


Figure 17. Composite Photograph of Preliminary Press-Swage Blind Fastener Shown in Photo (from top to bottom)
- the installed blind fastener
- the components of the blind fastener
- the adapted SPS DN512 press-nut hand tool used for installation

B. 2. Development of a Beryllium Blind Fastener for 800°F Application (continued)

a. Beryllium Press-Swage Blind Fastener (continued)

COLLAR INSTALLATION TO DETERMINE PRELOAD OR CLAMPING FORCE

Installation Torque inch-pounds	Collar Expansion from 0.312"Dia.	Clamping Force of Collar on Sleeve, pounds
Single Angle on Sleeve		
200	0.364	100
200	0.366	110
200	0.364	50
Double Angle on Sleeve		
80	0.324	-
120	0.352	-
160	0.360	285
180	0.362	400
200	0.365	500
200	-	600
200	-	580

The results indicated that the double angle on the sleeve was required to develop adequate preload or clamping force before insertion of the beryllium core bolt. They also showed that if failure did occur, it would probably be the stainless steel collar component that would fail, thereby avoiding any beryllium health hazard.

For the final design, the core bolt was changed to the 100° flush head configuration for both the protruding and flush head blind fastener system. Manufacturing and testing of #10, 1/4 inch and 5/16 inch fastener systems in the protruding head design were conducted. Installation was accomplished using a special mandrel adapted for use with a "Pop" Rivetool. This facilitated ease of collar installation during fastener assembly.

B. 2. Development of a Beryllium Blind Fastener for 800°F Application (continued)

b. Blind Fastener with Point Drive Core Bolt

This system as illustrated in Figure 18 was the first system to be evaluated and the inter-relationship of the fastener components was established during this investigation. The variables and areas investigated under these variables were:

Core Bolt Design	Sleeve Design	Collar Design	Lubricant
1. Hexagon Recess Dimension	1. Lead Angle	1. Material	MIL-T-5544
2. Head Configuration	2. Wall Thickness	a. 304 s/s	SPS K_2
3. Thread	3. Internal Thread Diameter	b. A-286	Dry Film
	4. Head Configuration	c. R-Monel	McLube 1704
		d. Pure Nickel	
		2. Wall Thickness	
		3. Collar Height	
		4. Swaging Loads	

1. Collar and Sleeve Design

Development of the collar and sleeve was run concurrently to determine the swaging loads with the optimum design. The test set-up shown in Figure 19 was used for these investigations. Various collar materials, lead angles and lubricants were investigated and evaluated. From the investigation it was concluded that the optimum collar design was that shown in Figure 20; and for the sleeve, it was that shown in Figure 21.

Of the collar materials evaluated, selection was narrowed to annealed 304 stainless steel and A-286. Swaging loads were comparable for both materials and either could be used. For higher strengths at elevated temperatures, A-286 collars would be preferred.

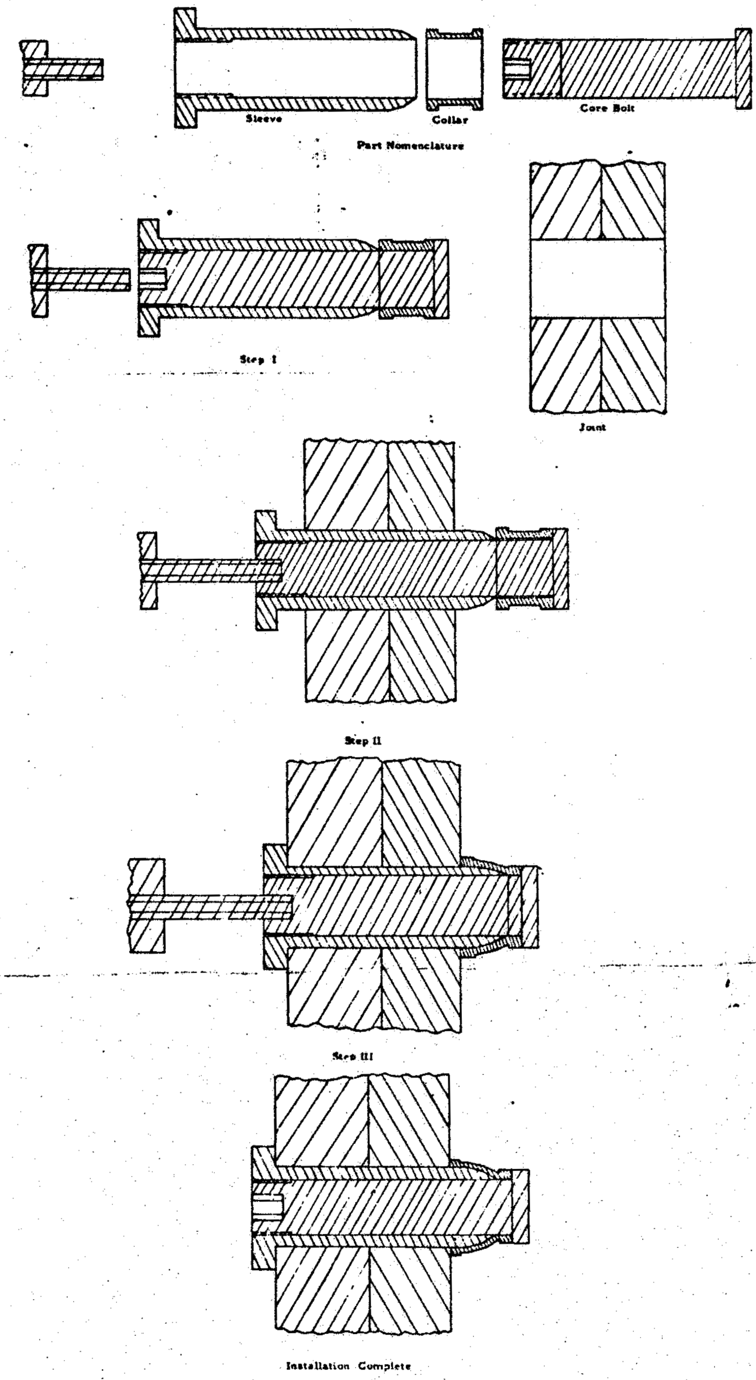


Figure 18. Installation Procedure for Beryllium Blind Fastener with Point Drive Core Bolt

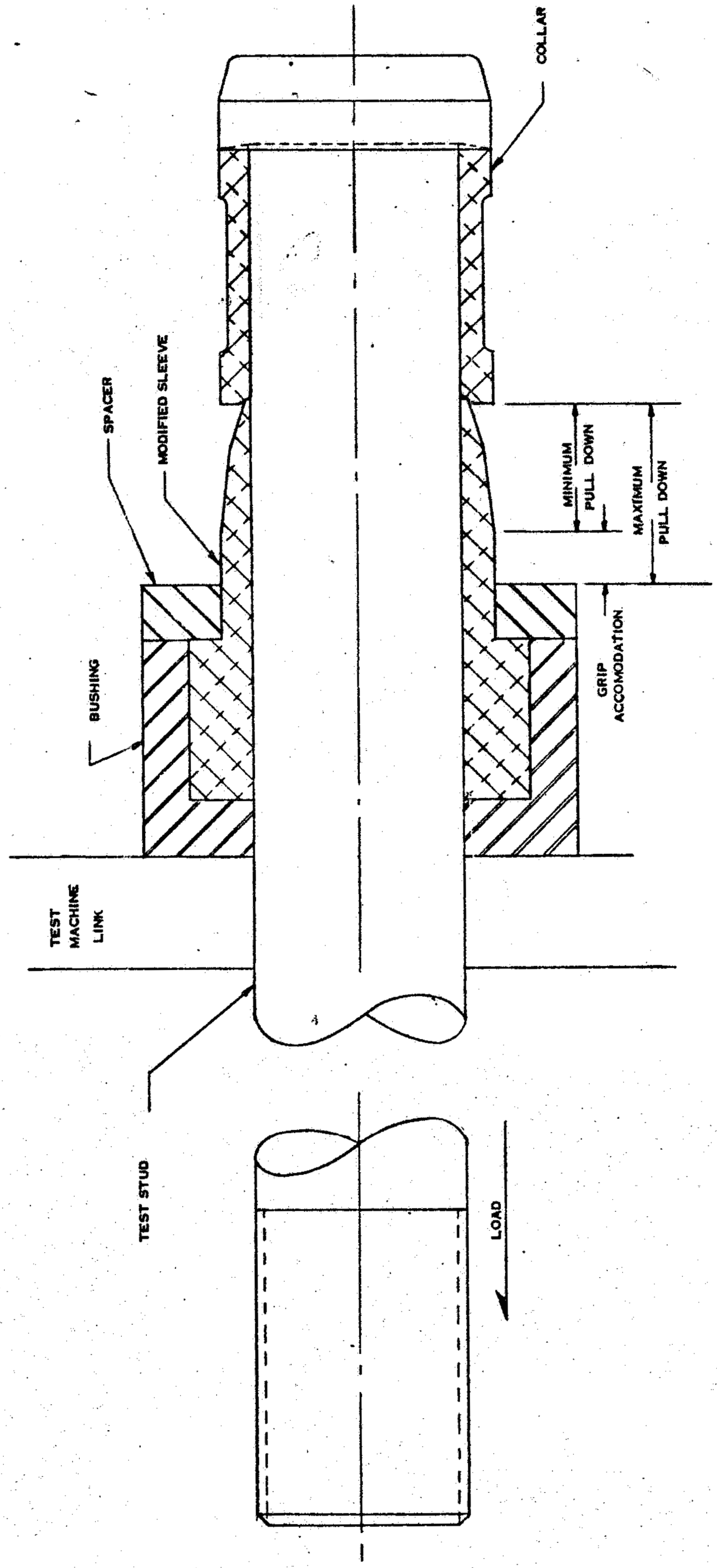


Figure 19. Test Set-Up To Simulate Installation of 5/16" Blind Fastener

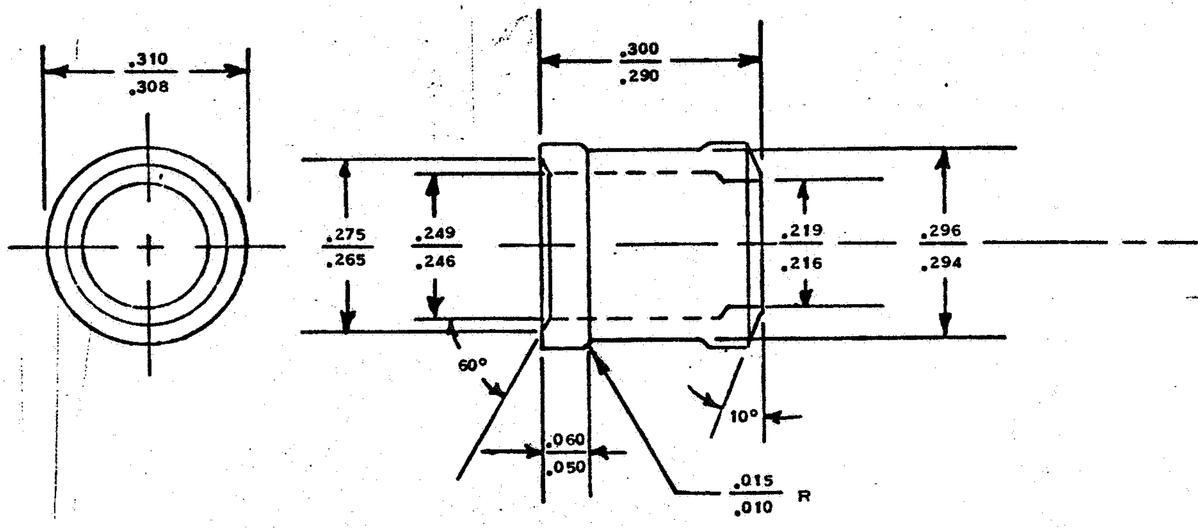


Figure 20. Proposed Collar (Annealed 304 s/s) For Beryllium Blind Fastener System

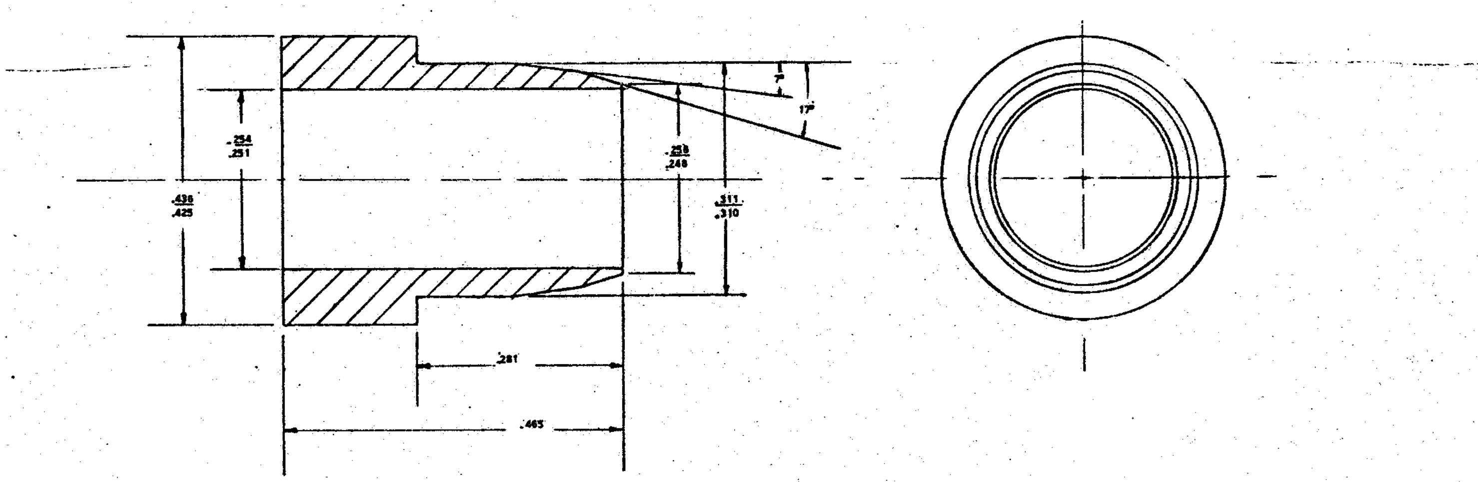


Figure 21. Simulated 5/16 inch Sleeve Used to Establish Optimum Sleeve Angle for Blind Fastener

B 2. Development of a Beryllium Blind Fastener for 800°F Application (continued)

1. Collar and Sleeve Design (continued)

Employing the optimum configuration for the sleeve and collar, swaging loads were as follows:

Collar Material	Swaging Load, pounds	Lubricant
304 s/s	680	MIL-T-5544
304 s/s	800	MIL-T-5544
304 s/s	750	MIL-T-5544
A-286	700	MIL-T-5544
A-286	850	MIL-T-5544
A-286	850	MIL-T-5544

During this investigation, the aforementioned lubricants were evaluated and it was concluded that MIL-T-5544 anti-seize lubricant would be the optimum lubricant to prevent galling and reduce installation torques to a minimum.

2. Core Bolt Design

Since the maximum compressive swaging load for collars was 850 pounds, tensile strength of the selected #12-28 core bolts had to be known to be sure that it exceeded this value. Bolts with MIL-S-8879 threads at a thread depth of 55 percent were tensile tested with the following results.

Ultimate Load, pounds	Ultimate Stress, psi (1)	Location of Failure
1100	43,000	Thread
1000	39,000	Head
1200	47,000	Head
1100	43,000	Shank
1300	50,000	Head
2000	77,500	Thread

(1) Stress calculated at the Tensile Stress Area of 0.02579 square inches.

B. Development of a Beryllium Blind Fastener for 800°F Application (continued)

2. Core Bolt Design (continued)

The results showed that the bolt tensile strength was border line for obtaining complete swaging of the collar. However, with bolt and swaging loads established, work was conducted for determining optimum hexagon recess configuration at the thread point. A hexagon configuration with an across flat dimension of 0.094 inches at a depth of 0.109 inches was initially tried. Manual installation employing a hexagon wrench for driving resulted in failure at the base of the hexagon recess. The across flat dimension was then decreased to 0.078 inches but the same type of failure resulted. It was, therefore, decided to extend the depth of the recess into the shank of core bolt as illustrated in Figure 22. Full installation was accomplished with this design. A fully installed system is depicted in Figure 23. While the extended depth of the recess into the bolt shank was beneficial for installation, it had an adverse effect on the tensile strength. Tensile strength decreased significantly when compared to assemblies installed by an external hexagon drive. Tensile strengths for the both systems were:

Driving Configuration	Installation Torque in-lbs.	Collar Expansion in.	Ultimate Load lbs.	Location of failure
Ext. Hexagon	50	0.368	1960	Head
Ext. Hexagon	25	0.363	1420	Head
Int. Hexagon	26	0.358	960	Thread Runout

Although double shear tests were not conducted, it was expected that the double shear strength would also decrease because of the extended depth of the recess.

In any event, it was concluded that a beryllium blind fastener with the point drive core bolt for driving would not be feasible for practical application.

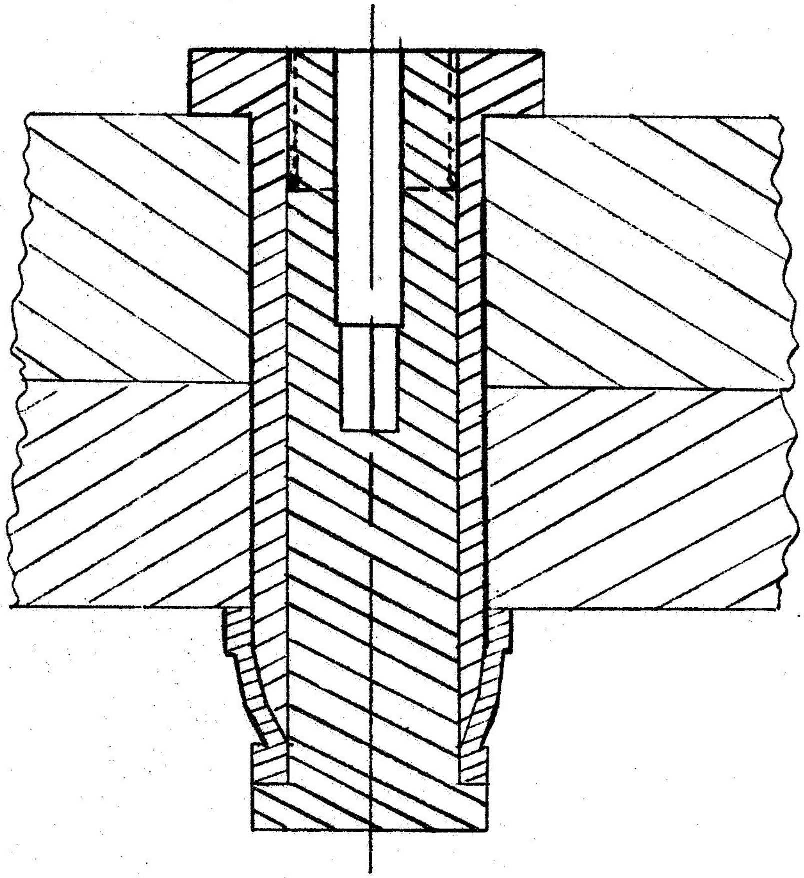


Figure 22. Schematic Drawing of Installed Blind Fastener with Point Drive Bolt Illustrating Extended Hexagon Recess Into Core Bolt Shank.

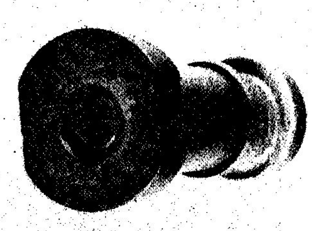


Figure 23. Assembled Beryllium Blind Fastener System with Hex Recess Located in Shank of Core Bolt.

B. 2. Development of a Beryllium Blind Fastener for 800°F Application (continued)

c. Blind Fastener with Permanent Hexagon External Drive

Since the internal hexagon drive was not feasible, use of a permanent external hexagon drive was considered. A sketch of this sytem is illustrated in Figure 24.

Many problems were encountered in an attempt to develop this system. One of the prime problems was the fabrication of the tapped beryllium sleeves. The sleeves which were made of XT-20 material were forward extruded at SPS for higher strength. High rejection rates were encountered during fabrication mainly in cracked sleeves. Delaminations, the cause of the majority of sleeve cracking occurred during the etching cycle. A representative photograph of this type of cracking is shown in Figure 25.

It was, therefore, decided to abandon the approach of drilling and tapping the sleeve to accommodate the core bolt. Also, since the permanent hexagon drive did not lend itself for adaptability for both a protruding and flush head system, it was dropped from further consideration.

d. Stainless Steel Elliptical Press Nuts with Beryllium Core Bolts

The development of a blind fastener with a buckling type collar was investigated (Figure 26). Stainless steel elliptical press nuts were selected for the evaluation. The press nuts in a 1/4-28 diameter were manually installed with a mandrel into a 0.312 inch thick beryllium sheet. After installation of the press nut, 1/4-28 XT-20 beryllium hexagon head bolts were assembled into the press nut. The installed fasteners are depicted in Figure 27. For this operation, the installation loads of the press nut ranged from 3,250 pounds to 4059 pounds. It was concluded, however, that installation loads of this magnitude would be too severe for installing in thin sheet beryllium. Consequently, further investigation of this system was discontinued.

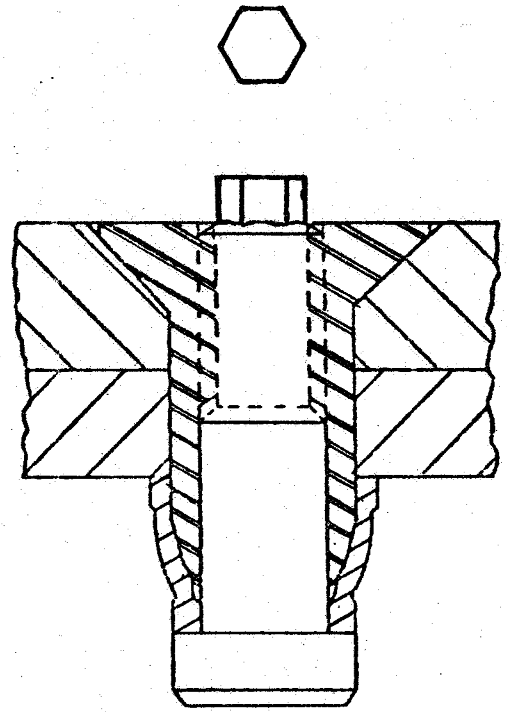
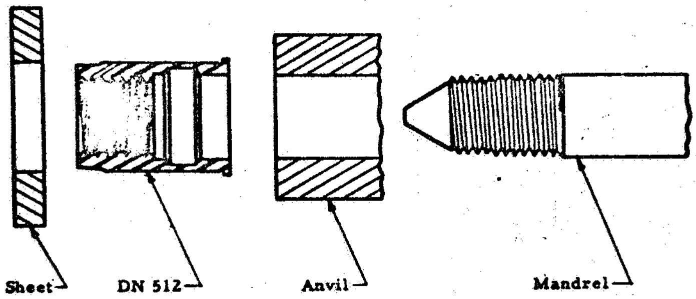
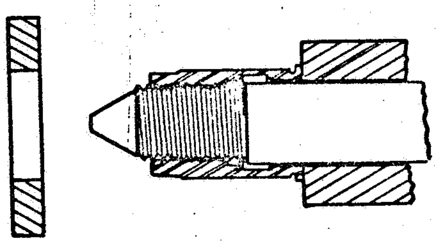


Figure 24. Proposed Permanent Hexagon Drive for Protruding Head Beryllium Blind Fastener System.

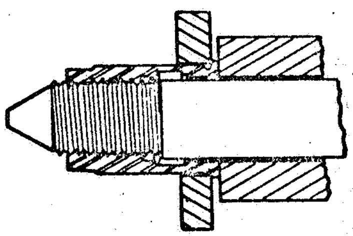
Figure 25. Beryllium Sleeves - Extruded, Machined, Drilled, Tapped, and Etched. No visual cracks were apparent before immersion in etching solution.



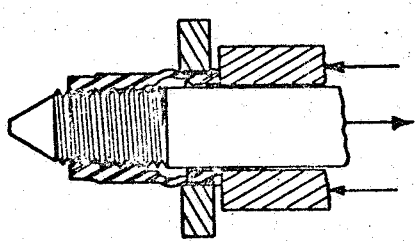
1. Required Parts



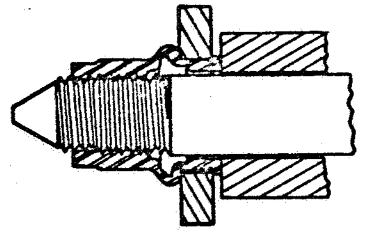
2. The nut is threaded on the mandrel snug against the anvil, so that 1 to 3 threads pass through nut.



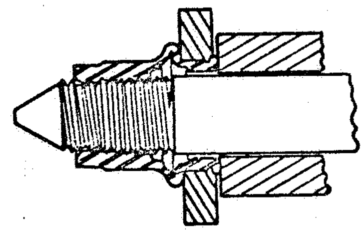
3. Nut is inserted into workpiece.



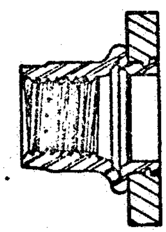
4. Axial load is applied. Note direction of forces. Swage starts in recessed section.



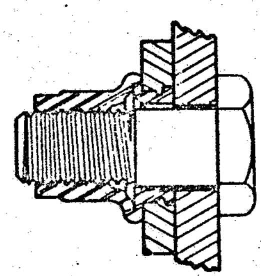
5. Swaged section seats on sheet.



6. Anvil pressure forces knurl into sheet.



7. Knurl fully seated at recommended installation pressure. Mandrel withdrawn.



8. Joint completed.

Figure 26. Installation Instructions for SPS Self Locking Press Nut

Figure 27. Stainless Steel Elliptical Press Nuts, 1/4-28 Beryllium Hex Head Bolts in 0.312 inches Beryllium Sheet

B 2. Development of Beryllium Blind Fastener for 800°F Application (continued)

3. Aluminum-Beryllium System

For a short time at the beginning of the program, aluminum was considered as a possible candidate for one or more of the parts of the blind fastener. The most logical part to be made of aluminum would be the deformable collar or nut.

The developmental work performed on the collar was directed toward getting the high tensile strength of the target requirement.

Work was initiated on 2024-T4, 2014-T4, and 7075-T6 aluminum alloys for the collar as shown in Figure 28.

The variable of material, design, dimension, lead angle, and lubricants were given a preliminary investigation.

The conclusion was that an aluminum collar system would be feasible using a 2024-T4 aluminum collar with Molybdenum disulphide. (See Figure 29)

4. Testing

The objectives of the test program for the blind fastener were to supply limited data on the tensile and double shear properties of the beryllium blind fastener designed and manufactured during the course of this contract. The test program consisted of preload determination, tensile tests at room and 800°F for the #10, 1/4, 5/16 inch systems. The total number of fasteners of each size which were tested was dependent upon the difficulties encountered during manufacture and testing. The test results for the #10, 1/4, and 5/16 inch Press-Swage blind fastener are tabulated in Table X, XI, and XII.

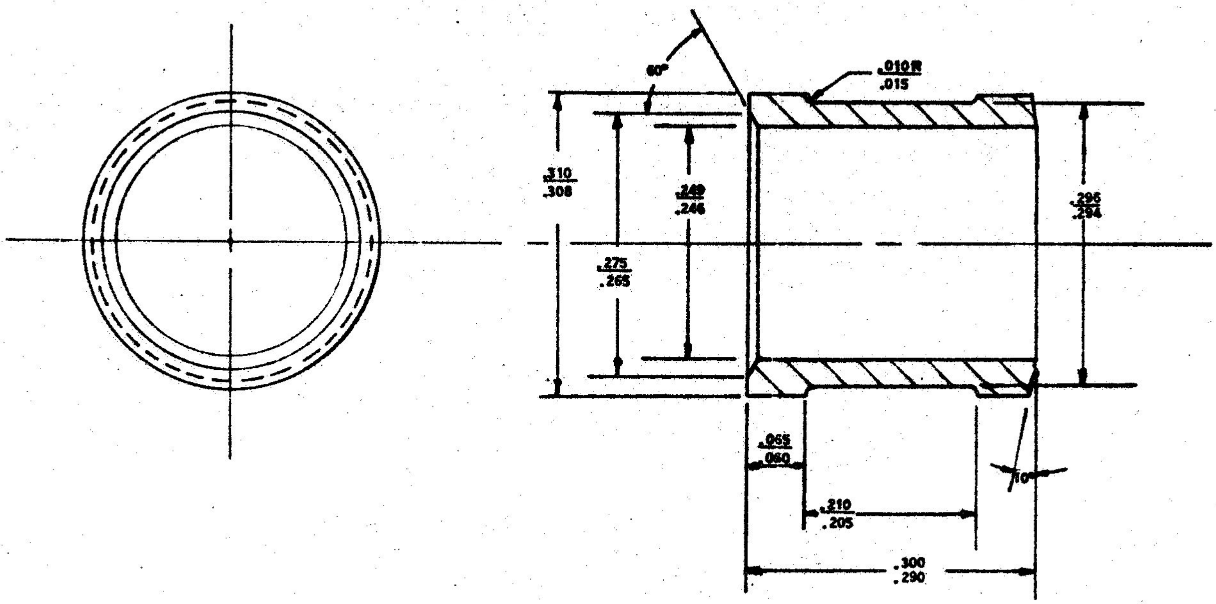
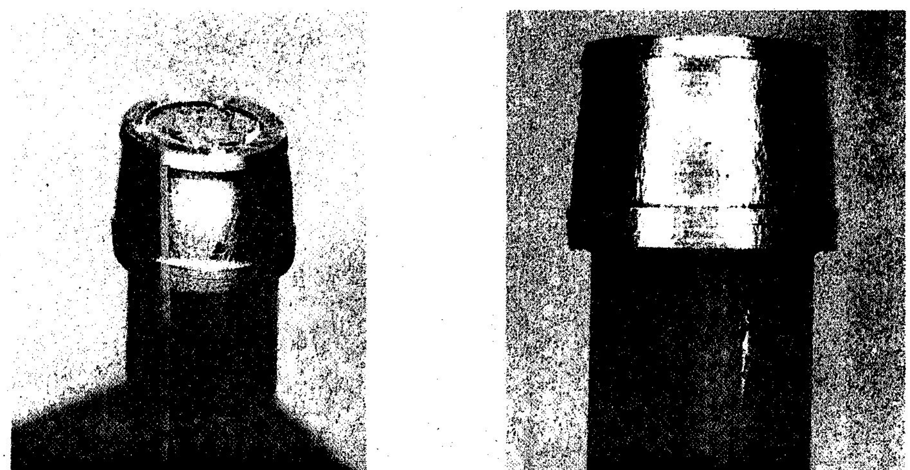


Figure 28. Final Collar Dimensions for 5/16 inch System with a Beryllium Core Bolt and with an Aluminum Collar & Sleeve.



Mag. X2.7 Mag X4

Figure 29. Photographs of a 2024-T4 Aluminum Collar Swaged on a Simulated Sleeve

Sleeve was coated with a dry film lubricant of Molybdenum Disulphide prior to swaging.

TABLE X

MECHANICAL PROPERTIES OF 5/16-24 BERYLLIUM PROTRUDING HEAD PRESTRESSED FASTENER SYSTEM
(Fastener Program for Contract NAS8-20158)

Part No. Bolt: PDP 16-10-24
Configuration: Protuding Hd. Pt. Drive

Material: Berylco XT-20
Condition: Forward Extruded @ 1000°F-1100°F(50% Reduction)

Nut: TN 12-10
Configuration: Twist-Off Nut

Material: 347 Stainless Steel
Condition: Annealed

Diameter: 5/16-24 (55% thread height)

1. Tensile

a. Base Material Properties -0.113 inch specimen

Test No.	Test Temp. °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation 0.5 in. gage lgth. %	Reduction of Area, %
1	Room	101,000	83,300	4.0	5.5
2	Room	99,500	84,300	4.0	3.5
3	Room	100,500	80,000	4.0	2.0
4	800	50,700	47,000	8.0	25.0
5	800	56,300	56,300	10.0	29.0
6	800	50,900	49,500	10.0	31.5

b. Bolt Properties

Test No.	Test Temp. °F	Preload, pounds	Preload Stress, psi(1)	Ultimate Load, pounds	Ultimate Stress, psi (1)
7(a)	Room	1,325	22,800	5,760 (H)	99,200
8(a)	Room	1,325	23,000	5,300 (H)	91,500
9	Room			5,440 (H)	94,000
10	800			3,425 (H)	59,000
11	800			3,240 (H)	55,800
12	800			3,400 (H)	58,600

(1) Stress calculated at the Tensile Stress Area of 0.05805 sq. inches.
(a) Twist-off nuts were coated with a lubricant per MIL-T-5544 Spec. prior to installation.
(H) Head Failure

TABLE X (continued)

2. Double Shear

Test No.	Test Temperature, °F	Ultimate Load, pounds	Ultimate Stress, psi (2)
1	Room	12,100	79,100
2	Room	12,600	82,400
3	Room	12,200	79,700
4	Room	12,400	80,900
5	Room	13,000	84,800
6	800	4,800	31,400
7	800	5,000	32,700
8	800	5,400	35,300

(2) Stress calculated at Twice Nominal Diameter Area, 0.1530 square inches.

3. Tension-Tension Fatigue @ Room Temperature

Minimum Load,	236 pounds;	4,500 psi (3)
Maximum Load,	2,359 pounds;	45,000 psi (3)

Test No.	Cycles to Failure	Location of Failure
1	1,493,000	Thread
2	662,900	Thread
3	1,070,900	Thread

(3) Stress calculated at the Basic Minor Diameter Area of 0.05242 square inches.

4. Torque Versus Induced Load

Nut coated with lubricant per Mil-T-5544 prior to installation

Torque, inch-pounds	Load, pounds Test No. 1	Test No. 2
50	870	840
100	1,450	1,250
150	2,500	3,340
200	3,060	4,160
250	3,700	4,300 (H)
300	3,860	
350	4,100 (T)	

(H) Head Failure
(T) Thread Failure

TABLE XI

MECHANICAL PROPERTIES OF 5/16-24 BERYLLIUM FLUSH HEAD PRESTRESSED FASTENER SYSTEM

Part No. Bolt : PTF 16-5-12
Configuration: 100° Flush Hd. Pt. Drive

Material: Berylco XT-20
Condition - Forward Extruded @ 1000°F-1100°F (50% Reduction)

Nut: TN 12-10
Configuration: Twist-Off Nut

Material: 347 Stainless Steel
Condition: Annealed

Diameter: 5/16-24 (55% Thread Height)

1. Tensile

a. Base Material Properties - 0.113 inch specimens

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation 0.5 in. gage lgth. %	Reduction of Area, %
1	Room	101,000	83,300	4.0	5.5
2	Room	99,500	84,300	4.0	3.5
3	Room	100,000	80,000	4.0	2.0
4	800	50,700	47,000	8.0	25.0
5	800	56,300	56,300	10.0	29.0
6	800	50,900	49,500	10.0	31.5

b. Bolt Properties

Test No.	Test Temperature, °F	Preload, pounds	Preload Stress, psi(1)	Ultimate Load, pounds	Ultimate Stress, psi (1)
7	Room	1450	25,000	2950(H)	50,800
8	Room	925	15,900	2720(H)	46,900
9	Room	1030	17,700	1880(H)	32,400
10(a)	Room			4850(T)	83,500
11(a)	Room			4750(H)	81,800
12	800			1970(H)	33,900
13	800			1600(H)	27,600
14	800			2125(H)	36,600

(1) Stress calculated at the Tensile Stress Area of 0.05805 square inches.
(a) Head band O.D. Height .062 inches
(H)- Head Failure
(T)- Bolt Thread Failure

TABLE XI (continued)

2. Double Shear

Test No.	Test Temperature, °F	Ultimate Load, pounds	Ultimate Stress, psi (2)
1	Room	12,100	79,100
2	Room	12,600	82,400
3	Room	12,200	79,700
4	Room	12,400	80,900
5	Room	13,000	84,800
6	800	4,800	31,400
7	800	5,000	32,700
8	800	5,400	35,300

(2) Stress calculated at Twice Nominal Diameter Area, 0.1530 square inches.

3. Tension-Tension Fatigue @ Room Temperature

Minimum Load, 236 pounds; 4500 psi (3)
Maximum Load, 2,359 pounds; 45,000 psi (3)

Test No.	Cycles to Failure	Location of Failure
1	11,400	Head
2	Head fractured during initial loading	

(3) Stress calculated at the Basic Minor Diameter Area of 0.05242 square inches.

TABLE XII

TEST RESULTS FOR #10 BERYLLIUM BLIND FASTENER

Tensile Strength Data

Specimen Number	Test Temperature	Collar Expansion from, inches	Collar Expansion to, inches	Collar Preload, pounds	Ultimate Strength, pounds	Ultimate Strength, psi (1)	Failure Location
1	Room	0.190	0.222	90	550	60,500	Head
2	Room	0.190	0.220	100	626	69,000	Head
3	Room	0.190	0.220	110	450	49,500	Head
4	800°F				455	50,000	Collar
5	800°F				415	45,700	Collar

(1) Stress calculated at the Tensile Stress Area of #6-32 Thread, 0.009085 square inches
Collars made from 304 stainless steel

TABLE XII (continued)

TEST RESULTS FOR #10 BERYLLIUM BLIND FASTENER

Double Shear Strength Data

Specimen Number	Test Temperature	Collar Expansion from, inches	Collar Expansion to, inches	Double Shear Strength, pounds	Double Shear Strength, psi (1)	Type of Failure
1	Room	0.190	0.220	3370	59,400	brittle
2	Room	0.190	0.219	3100	54,700	brittle
3	Room	0.190	0.219	3340	58,900	brittle
4	800°F	0.190	0.220	1400	24,700	ductile
5	800°F	0.190	0.219	1425	25,100	ductile

(1) Stress calculated at Twice Nominal Diameter Area, 0.0567 square inches

TABLE XIII

TEST RESULTS FOR 1/4" BERYLLIUM BLIND FASTENER

Tensile Strength Data

Specimen Number	Test Temperature	Collar Expansion from, inches	Collar Expansion to, inches	Collar Preload, pounds	Ultimate Strength, pounds	Ultimate Strength, psi (1)	Failure Location
1	Room	0.249	0.280	104	920	46,000	Thread
2	Room	0.249	0.280	132	1020	51,000	Thread stripped from collar
3	Room	0.249	0.280	126	810	40,500	Low value due to collar misalignment
4	800°F				1200	60,000	Collar
5	800°F				615	30,800	Collar

(1) Stress calculated at the Tensile Stress Area of a #10-32 Thread, 0.01999 square inches
Collars made from 304 stainless steel

TABLE XIII (continued)

TEST RESULTS FOR 1/4" BERYLLIUM BLIND FASTENER

Double Shear Strength Data

Specimen Number	Test Temperature	Collar Expansion from, inches	Collar Expansion to, inches	Double Shear Strength, pounds	Double Shear Strength, psi (1)	Type of Failure
1	Room	0.248	0.290	4,760	48,500	brittle
2	Room	0.248	0.289	6,480	66,000	brittle
3	Room	0.248	0.290	4,740	48,400	brittle
4	800°F	0.249	0.291	3,150	32,180	ductile
5	800°F	0.249	0.281	2,860	29,200	ductile

(1) Stress calculated at Twice Nominal Diameter Area, 0.09817 square inches

TABLE XIV

TEST RESULTS FOR 5/16" BERYLLIUM BLIND FASTENER

Tensile Strength Data

Specimen Number	Test Temperature	Collar Expansion from, inches	Collar Expansion to, inches	Collar Preload, pounds	Ultimate Strength, pounds	Ultimate Strength, psi (1)	Failure Location
1	Room	0.308	0.366	274	1,350	52,300	Thread
2	Room	0.308	0.365	285	1,600	62,000	Thread runout
3	Room	0.308	0.366	220	1,480	57,400	Fillet failure
4	800°F				1,480	57,400	Collar
5	800°F				1,725	66,900	Collar
6	800°F				1,290	50,000	Collar
7	800°F				1,575	61,100	Collar

(1) Stress calculated at the Tensile Stress Area of #12-28 Thread, 0.02579 square inches
Collars for specimens 1 through 5 made of 304 stainless steel; collars for specimens 6 and 7 made from A-286

TABLE XIV(continued)

TEST RESULTS FOR 5/16" BERYLLIUM BLIND FASTENER

Double Shear Strength Data

Specimen Number	Test Temperature	Collar Expansion from, inches	Collar Expansion to, inches	Double Shear Strength, pounds	Double Shear Strength, psi (1)	Type of Failure
1	Room	0.308	0.369	6,540	42,700	brittle
2	Room	0.308	0.369	7,500	48,900	brittle
3	Room	0.308	0.369	7,440	48,500	brittle
4	800°F			4,615	30,100	ductile
5	800°F			4,105	26,800	ductile

(1) Stress calculated at Twice Nominal Diameter Area, 0.1530 square inches

SECTION VI

FABRICABILITY INVESTIGATION

Though much is known about general machinability characteristics of beryllium, the existing techniques had to be adapted to the manufacture of fasteners. In addition, the mechanical property goals of the fastener systems made it essential that the bolts have upset heads and rolled threads. Very little work has been accomplished in reducing these two fastener production techniques to science.

The manufacturing methods investigated for 5/16-24 bolts were:

Forging	Thread Rolling
Forward Extrusion	Drilling and Broaching
Grinding	Etching
	Inspection

A. Forging

Forging investigations were conducted for the five grades of beryllium listed in Table I. In addition to these grades, Beryllium Corporation and Brush Beryllium Company submitted sample heats of other grades for investigation of forging characteristics. These materials are listed in Table XIV.

Forging characteristics were investigated employing various head configurations. These consisted of protruding round head (pan head), hexagon head, and buttonhead. Figures 30 and 31 show the die configurations for the protruding round head and for the hexagon head which were used for most of the studies.

In all forging investigations conducted for this contract, a crack-free head could not be formed on any of the materials by hot upsetting. Typical failures are depicted in Figure 32 through 34. Forging temperatures ranged from 900°F to 1800°F. Surface preparation prior to forging was varied to include machined surface, machined and etched surfaces, and completely etched surfaces. A portion of the results of the forging investigation are tabulated in Table XV.

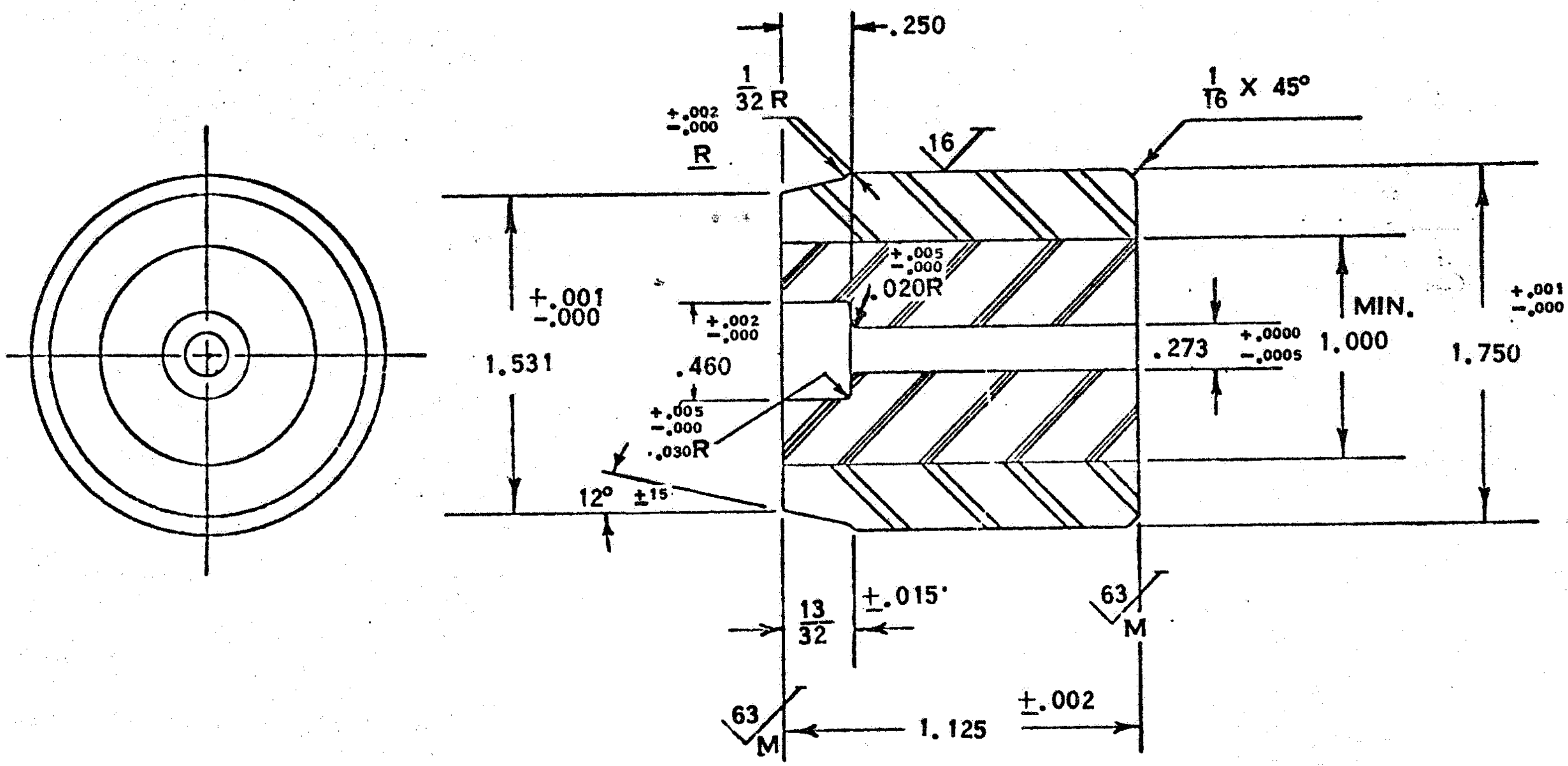
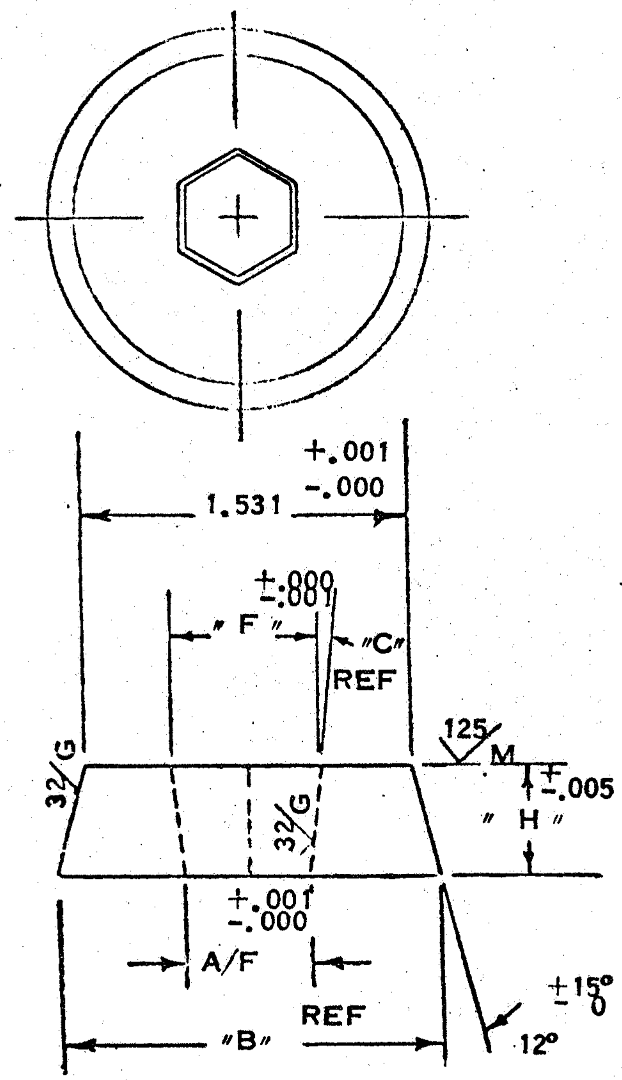


Figure 30. Carbide "A" Spacer for Forged Blank Beryllium Material (Hot Press)



Part No. 3205	A/F	"F"	"C" REF	"H"	"B"
843452	.383	.386	10°	.500	1.744
843453	.446	.449	10°	.500	1.744
843454	.511	.514	10°	.500	1.744
843619	.440	.443	12°	.437	1.716
844308	.358	.361	21°	.250	1.637

RUNOUT BETWEEN I.D. & O.D's
NOT TO EXCEED .001 T.I.R.

USE RING GAGE No. 85-16

TOLERANCES UNLESS SPECIFIED
DECIMAL 1/64 SURFACE FIN, 63_M

MAT'L	H.T.
M50	58-60RC

Figure 31. Hexagon Configuration Head Spacer Die

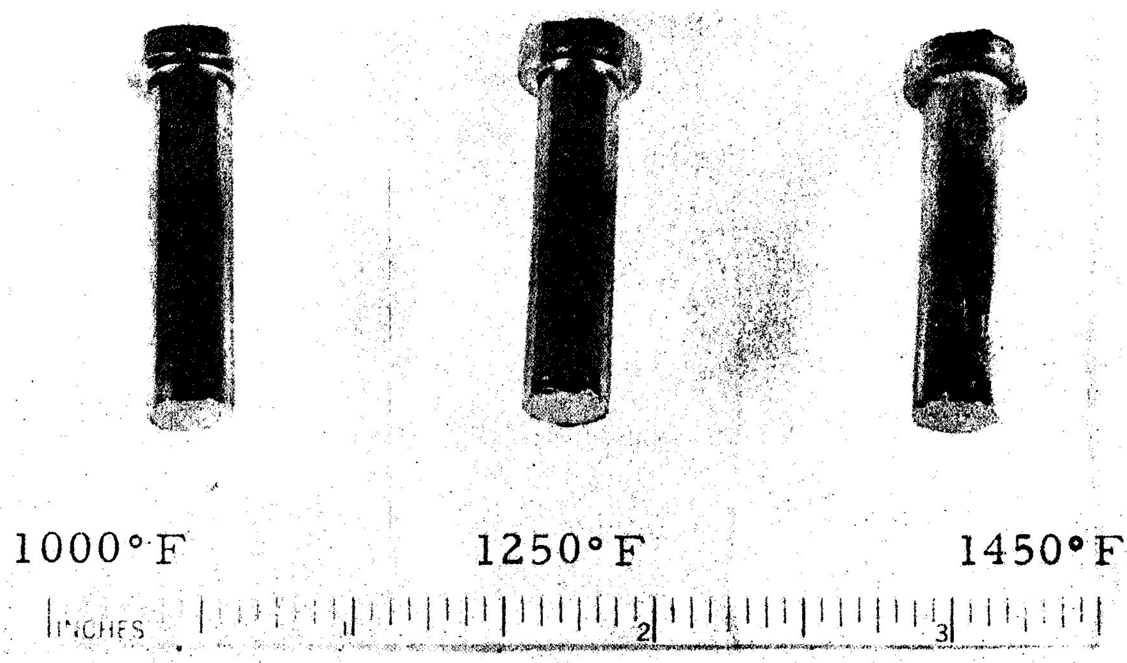


Figure 32. Photograph of Hot Forged Berylco Material with Protruding Type Head

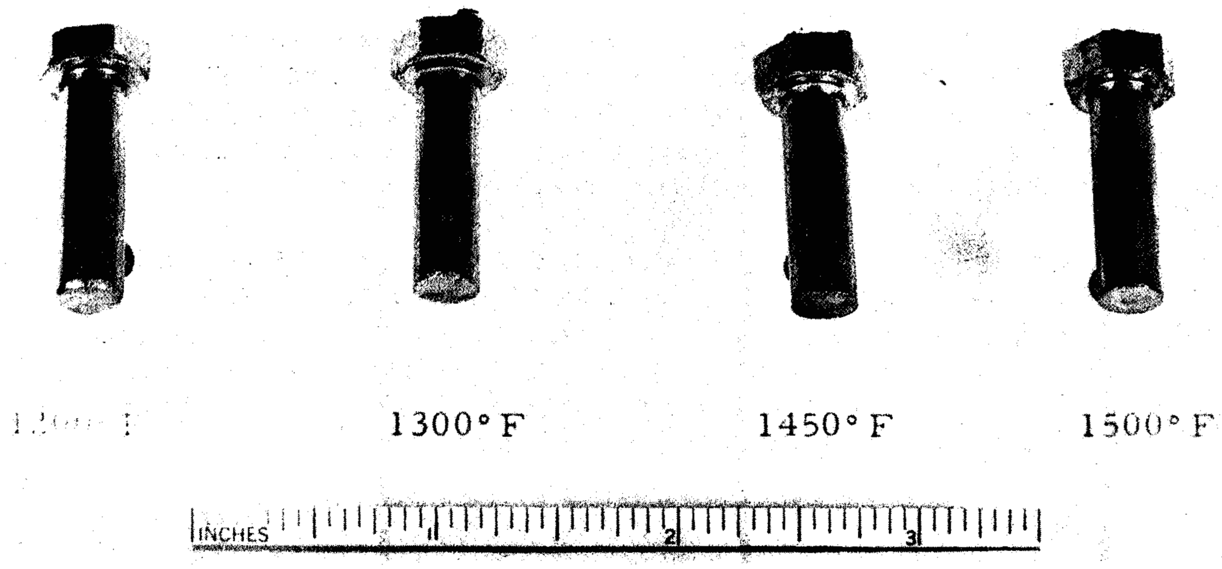


Figure 33. Photograph of Hot Forged Brush Beryllium Material with Hexagon Type Head.

Figure 34. Photograph of Hot Forge Beryllium Metals Beryllium Material with Button Type Head

A. Forging (continued)

Beryllium Corporation was contacted and informed of these results. They suggested a heat treatment of 1290°F (700°C) for 48 hours prior to hot forging and then forge at 1200°F. They reported that this treatment greatly improved material ductility at 1000°F with no change in strength properties.

Forging of the Brush SP 100-C and Berylco PX-12, and XT-20 materials that underwent the 1290°F treatment did show an improvement in forging characteristics. However, surface cracks were still evident after forging. In some instances, the cracks were removed by subsequent machining but not enough to warrant further investigations along those lines.

From these results, it was suspected that the beryllium materials supplied for evaluation possessed inherently poor forging characteristics for fastener application. To prove this point, beryllium material evaluated in 1959 under Air Force Contract AF33(600)-39728 was prepared for forging. This material was selected because it exhibited good forging characteristics which are reported in AMC Technical Report 600-7-807. A few threaded studs were available which were machined and etched to forging diameter. Forging blanks of Berylco XT-20 material were similarly prepared. The blanks of both materials were then forged at 1000°F using the protruding round head dies illustrated in Figure 30. Visual examination of the forged blanks revealed that the XT-20 material still exhibited the typical longitudinal cracks in the head area. There were no indications of cracks on the other material. The forged blanks of both materials are shown in Figure 35. The supplier of the forgeable grade of material is not certain but it was either Brush Beryllium Company or Beryllium Corporation. They were the only companies to supply material for the 1959 Air Force program.

It was, therefore, concluded that a forgeable grade of beryllium for fastener application was not available. However, Brush Beryllium Company in a cooperative program with SPS Laboratories developed a forgeable grade of beryllium for fastener application. Unfortunately, this material was developed at a time too late for inclusion in this program.

A. Forging (continued)

The material is capable of being upset two-and-half (2 1/2) head heights without any detrimental surface imperfections. Figure 36 depicts hot forged specimens of the Brush forgeable grade material and the Berylco XT-20 material that were upset 2 1/2 head heights.

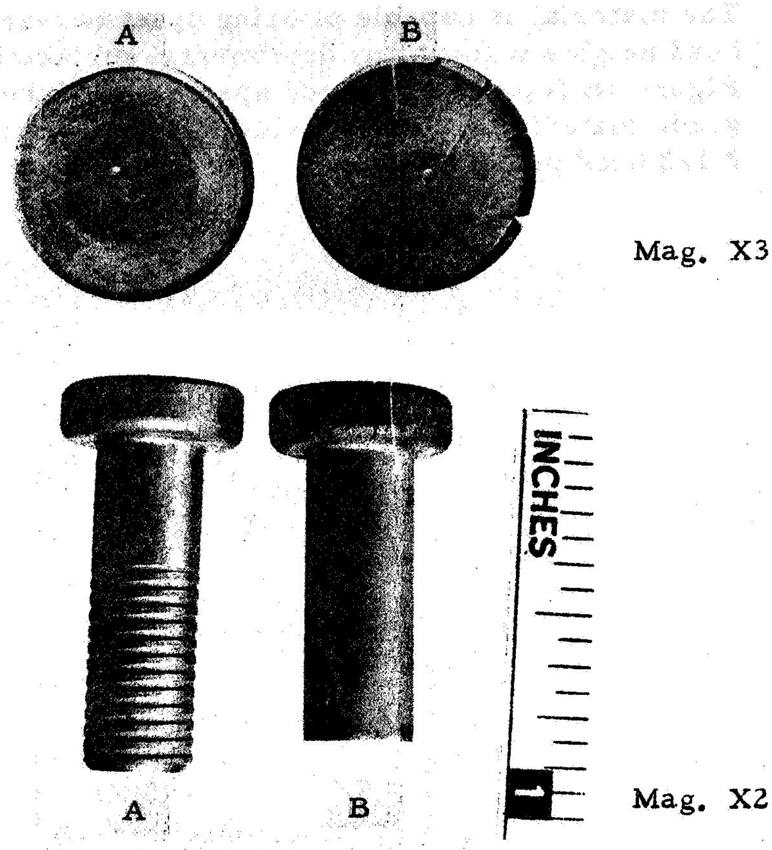


Figure 35. Protruding Head Configuration Forged on Beryllium Materials at 1000°F.

A. Material - Forging blanks machined and etched from beryllium threaded stud previously evaluated in Contract AF33(600)-39728. Note the absence of cracks. Supplier unknown (either Brush or Berylco).

B. Material - Berylco Material - XT-20, 75:1 extrusion reduction ratio. Forging blanks were machined and etched from 1/2 inch round material.

Both A and B were etched 0.004 inches/surface prior to forging.

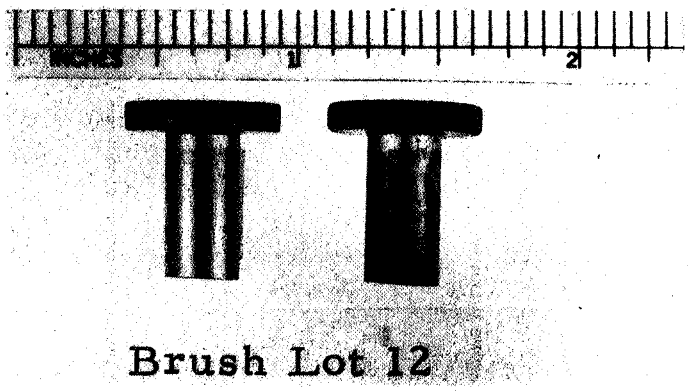


Figure 36. Photomacrograph of Hot Forged Specimens of Brush Beryllium Company Forgeable Grade Material and Beryllium Corporation XT-20 Material.

Specimens were hot-upset 2 1/2 head heights. Note the crack-free head of the Brush material. Specimens were forged at the optimum forging temperature for the Brush Material.

B. Forward Extrusion

Since the Brush forgeable grade of beryllium was not yet developed for fastener application, forward extrusion of a head was investigated. The Berylco XT-20 material was selected as the candidate material because of its availability and good tensile and double-shear properties.

Initial attempts to forward extrude a head on the XT-20 material were not successful. Rattlesnaked and/or cracked surfaces resulted. This was attributed to a combination of improper lubricant and insufficient coverage of the extrusion dies. The lubricant used was McGee Chemical Company's McLube Spray (M_oS_2-101).

Other lubricants investigated were:

(Lubricant A) Cadmium iodide crystals
M-12 (M_oS_2 paste)
and Spindle oil

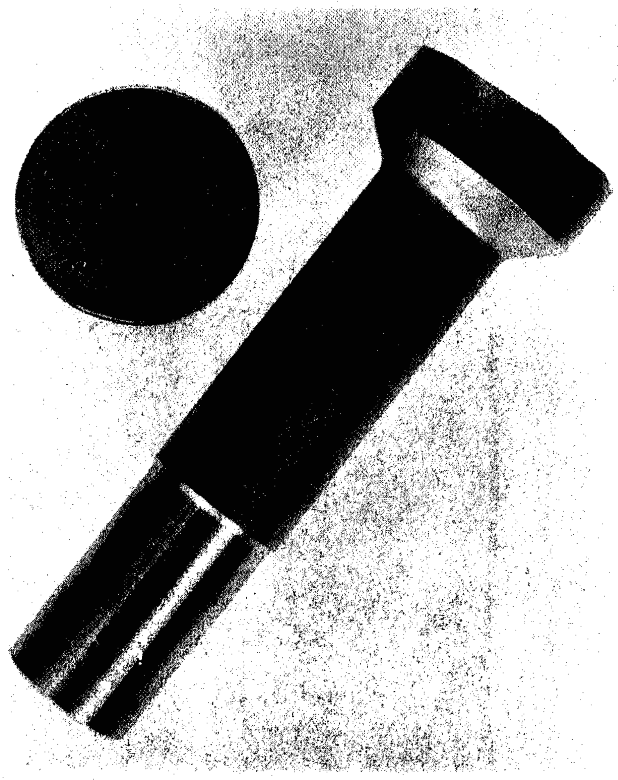
The materials were also mixed into a paste with the spindle oil acting as the binder.

(Lubricant B)	Die Gard	- 50% by Volume
	Light Lube Oil	- 10% by Volume
	M_oS_2 Powder	- Type K

These materials were also mixed into a paste with the light lube oil acting as the binder.

Lubricant B proved to be the most satisfactory of the lubricants tried and was subsequently used for all forward extrusion processing.

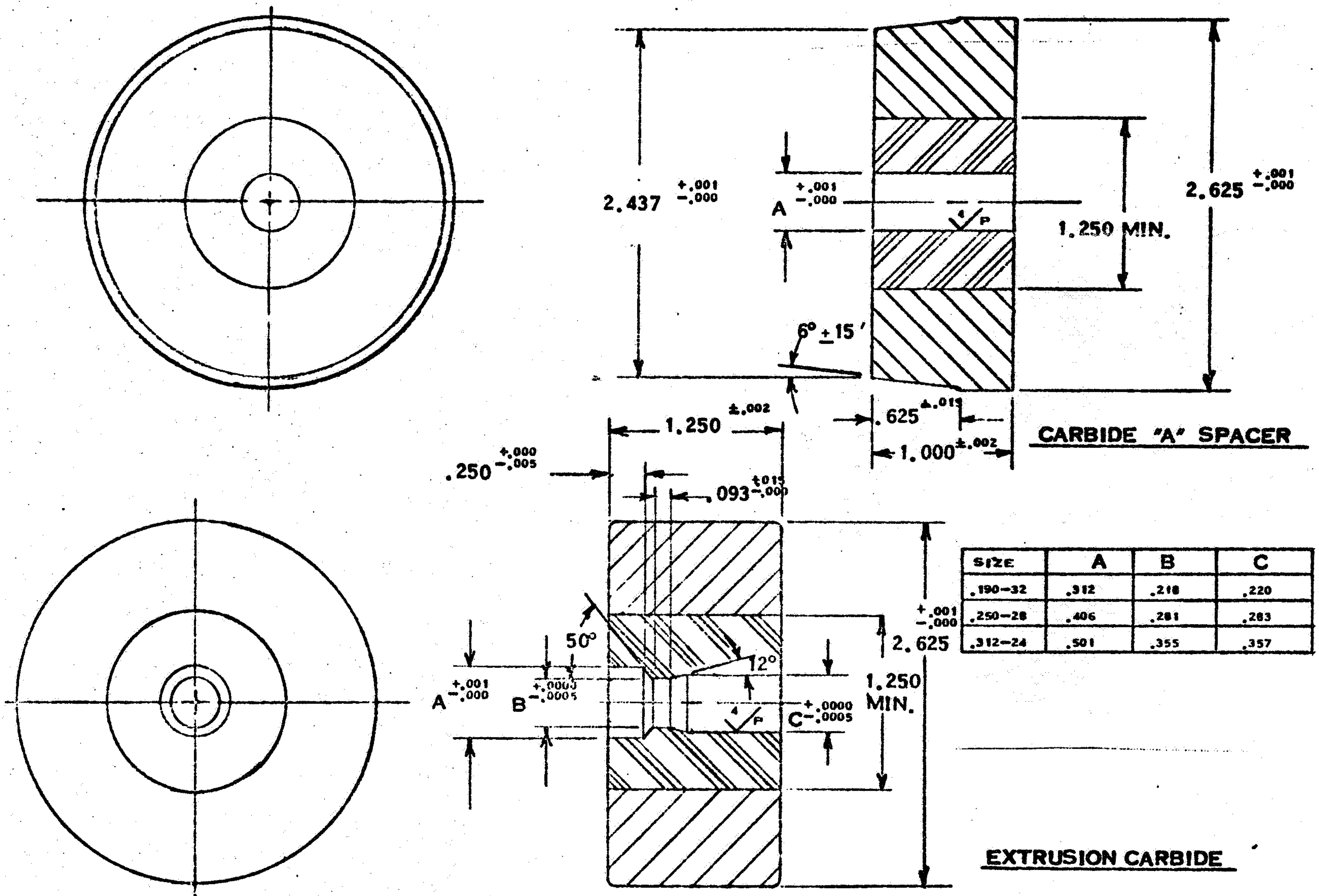
With the proper lubricant established, forward extrusion investigations were conducted with three Beryllium Corporation materials. These consisted of the XT-20, HP20 (Hot Pressed Block), and large diameter mill extruded bar material. Extrusion blanks from the three materials were machined and etched to a 0.494 inch diameter. They were then partially warm extruded in a confined die to a 0.350 inch diameter leaving a bulb like head at the unextruded end as shown in Figure 37. A 50 percent reduction of the cross sectional area was realized by the process. The extrusion die used for the study and all subsequent extrusion work is illustrated in Figure 38.



Mag. X2.7

Figure 37. Photograph of 5/16 inch Diameter Beryllium Bolt Blank with Forward Extruded Head.

Blank is in the "as-extruded" condition. Head configuration must be further machined to finished dimensions.



SIZE	A	B	C
.190–32	.312	.218	.220
.250–28	.406	.281	.283
.312–24	.501	.355	.357

Figure 38. Engineering Drawing for Forward Extrusion Die

B. Forward Extrusion (continued)

For the extrusion operation, the blanks were induction heated to 1100°F - 1150°F; placed in the die and forward extruded at a very high velocity. Prior to extrusion, the dies were coated with Lubricant B.

The extruded blanks were centerless ground and etched to a 0.312 inch diameter and double shear tested to determine the effect of the extrusion process on the shear properties. The results of the shear tests tabulated in Table XVI show that the shear properties of the XT-20 material were not affected by the extrusion process. Although the mode of fracture was considered ductile, it was not as ductile to the same extent as that exhibited by the unextruded XT-20 material listed in Table IV.

On the other hand, the shear properties of the forward extruded HP-20 and the large diameter mill extruded material were very low with brittle modes of fracture. Consequently, further evaluation of these two materials for the prestressed fastener system was discontinued.

The results listed in Table XVI further back up the conclusion that insufficient surface removal by etching after machining and grinding has a deleterious effect on the shear properties. Shear strength of the XT-20 material with surfaces either in the ground condition or in the etched (.001 inches/surfaces) condition were significantly lower than material that had a surface removal by etching of 0.004 inches per surface.

The investigation indicated that forward extruding a head on beryllium was feasible for fastener application. However, it does present certain limitations when compared to forging or hot upsetting a head. These would be:

Optimum Head Strength
Maximum Length of Bolt
Head Configuration
High Scrap Rate

B. Forward Extrusion (continued)

1. Optimum Head Strength

The full cross sectional area of the head of a forward extruded blank does not experience the work induced by the process. The work is concentrated in the area of the extrusion angle. When fabricating a protruding type head, the majority of the worked area is removed by machining. Consequently the head area becomes increasingly weaker. By hot upsetting, the head area becomes increasingly stronger. Figure 39 illustrates the flow pattern of the forward extruded head for the 5/16 diameter bolt.

2. Maximum Length of the Bolt

Present capabilities would be for a maximum length of 2 1/2 to 3 inches by extruding. For forging, it would be unlimited depending upon the type of forming press to be employed.

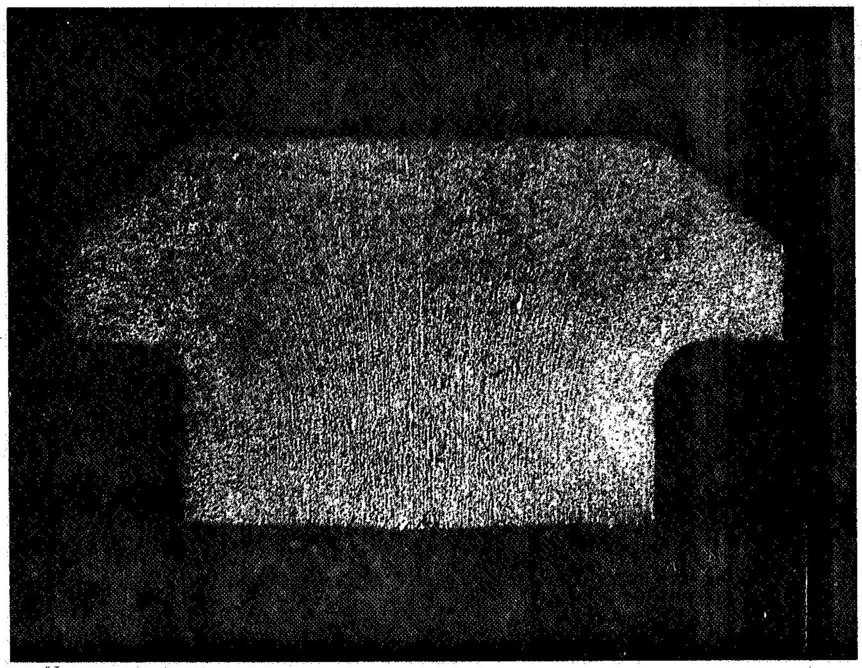
3. Head Configuration

Extruded heads are confined to simple shapes. Intricate shapes such as a 12-point external drive head would not be feasible. A hexagon type head would have to be machined and this would not be economical. These configurations would not present any problems when formed by the hot upsetting process.

4. High Scrap Rate

Cracking at the point is prevalent during the extrusion process. The length of the cracks usually run approximately 1/16 inches. This is subsequently cropped off which is uneconomical because of high cost of input material. In addition, it entails an extra operation.

Nevertheless, because a foregable grade of beryllium was not available, it was concluded that the XT-20 material with a forward extruded head would be the optimum material for fabrication into fasteners. This was based on feasibility of manufacture and mechanical properties.



Mag. X10

Figure 39. Photomacrograph of Forward Extruded Head of Berylco XT-20 Material

C. Grinding

Grinding operations were conducted on a No. "O" Cincinnati centerless grinder. A water soluble coolant of Hangstefers S-500 diluted 20 to 1 was used. Surface damage by the grinding operation was not considered too severe. Micro examination of the surface did reveal mechanical twinning to a depth of approximately 0.0015 inches. Figure 30 shows the microstructure at the surface of a Brush beryllium cylindrical specimen that was centerless ground.

Since a minimum of 0.004 inches per surface was removed by etching after grinding, centerless grinding was not considered detrimental. It would be recommended over machining because closer tolerances and concentricity can be held. This is particularly important for diameters prior to thread rolling where close tolerances and concentricity must be held.

D. Thread Rolling

Thread rolling was conducted on Reed A-22 and Waterbury-Farrell thread rolling machines. The Reed machine employs three cylindrical thread roll dies and the Waterbury-Farrell uses two reciprocating flat dies which exert pressure on the prepared blanks to form threads. The Waterbury-Farrell machine would be preferred. There is a tendency for threads to be tapered when rolled on the Reed, particularly for very stiff materials such as beryllium. The thread form,was in accordance with SPS-T-147 Specification which is listed in the Appendix. This stipulates a thread form in accordance with MIL-S-8879 but with a 55 percent thread depth. Previous work conducted under the Air Force beryllium fastener program showed that optimum properties are attained with this thread form.

Initially, threads were rolled on ground blanks 0.002 inches oversize. The threads were subsequently etched to finished dimensions. Examination of the threads revealed cracks at the thread crests which were not evident prior to etching. It was therefore decided to evaluate 5/16-24 protruding head bolts with threads in the unetched condition.

D. Thread Rolling (continued)

Test data presented in Table XVII indicated that threads in the unetched condition did not have an adverse effect on the bolt tensile properties. However, threads in the etched condition would be preferred to eliminate any surface defects that may be present.

Polarized light
Mag. X300

7732R

Figure 40. Photomicrostructure of the Ground Surface of a Brush Beryllium Cylindrical Specimen

Specimen was centerless ground on a No. "O" Cincinnati Centerless Grinder with a water soluble coolant. Note the mechanical twinned surface. (arrow)
Approximate depth is 0.0015 inches.

Photograph was submitted through the courtesy of the Brush Beryllium Company.

E. Drilling and Broaching

Drilling and broaching investigations were conducted to determine optimum configurations for the hexagon recess at the bolt point. Few problems were encountered during the drilling and broaching operations. High speed drills were first used for the drilling operation. These proved to be unsatisfactory because holes were found to be tapered. Carbide drills (Grade C-2) were then used with excellent results. Broaches of M-2 tool steel were used for the broaching operation. Both the drilling and broaching were accomplished on a 10 EE Monarch Engine Lathe .

Speeds and feeds for each operation were as follows:

Drilling:	1200 rpm - Hand Feed
Broaching:	400 rpm - 0.004 inches Feed

F. Etching

During Phase II, the following etchants were evaluated:

Etchant A

100 grams Chromic Acid (anhydride)
77 ml Phosphoric Acid
10 ml Concentrated Sulphuric Acid
50% by Volume Water

Etchant B

49% Volume Water
49% Volume Concentrated Nitric Acid
2% Volume Concentrated Hydrofluoric Acid

The evaluation of Etchant A showed that this etchant produces a film or crust on the etched surface. Unless it is removed by a cleaning process, it tends to obliterate any cracks which may be present. On the other hand surfaces etched with Etchant B are very clean and would be desired for overall fastener appearance. A survey of published literature on the etching of beryllium, showed that Etchant B or variations of it was the most frequently used. Therefore, Etchant B was selected as the etchant solution for all work conducted in Phase II and III.

F. Etching (continued)

For the process, plastic tanks were used to contain the etchant solution. Temperature was kept at 60°F to 90°F. Rate of surface removal was 0.0002 inches/surface/minute.

G. Inspection

Material was inspected upon receiving and during process for cracks, seams, and discontinuities.

Inspection procedures consisted of:

Fluorescent Penetrant Inspection
Metallurgical Inspection

1. Fluorescent Penetrant Inspection

Fluorescent penetrant inspection was used on blanks prior to forging, extrusion, thread rolling and on completed bolts. Surfaces required a light etch prior to inspection because the metal beryllium has a tendency to smear over cracks and seams during grinding operations.

Two types of penetrants were investigated. These were MET-L-CHEK and FL-50. The FL-50 is a penetrant recently developed by Testing Systems Incorporated. It is a water soluble self emulsifiable penetrant and proved to be the better of the two because of its ease of operations. It was also reported to be 100 times more sensitive than MET-L-CHEK and was therefore used for all non-destructive testing. It was found, however, that visual examination at 40x magnification was the best method of inspection for determining surface defects. The nature of defects, particularly in the thread area, encountered during the fabrication of beryllium fasteners showed that visual inspection was more reliable than fluorescent penetrant inspection.

G. Inspection (continued)

2. Metallurgical Inspection

Inspection of microstructure of "as-received" and "as extruded" material was conducted to determine the presence of cracks or internal ruptures. Figure 41 shows the microstructure of "as-received" Berylco XT-20 material in the longitudinal and transverse directions. And Figure 42 shows the microstructure of "as-extruded" Berylco XT-20 material in the longitudinal and transverse direction. These structures were typical for the Berylco XT-20 material investigated.

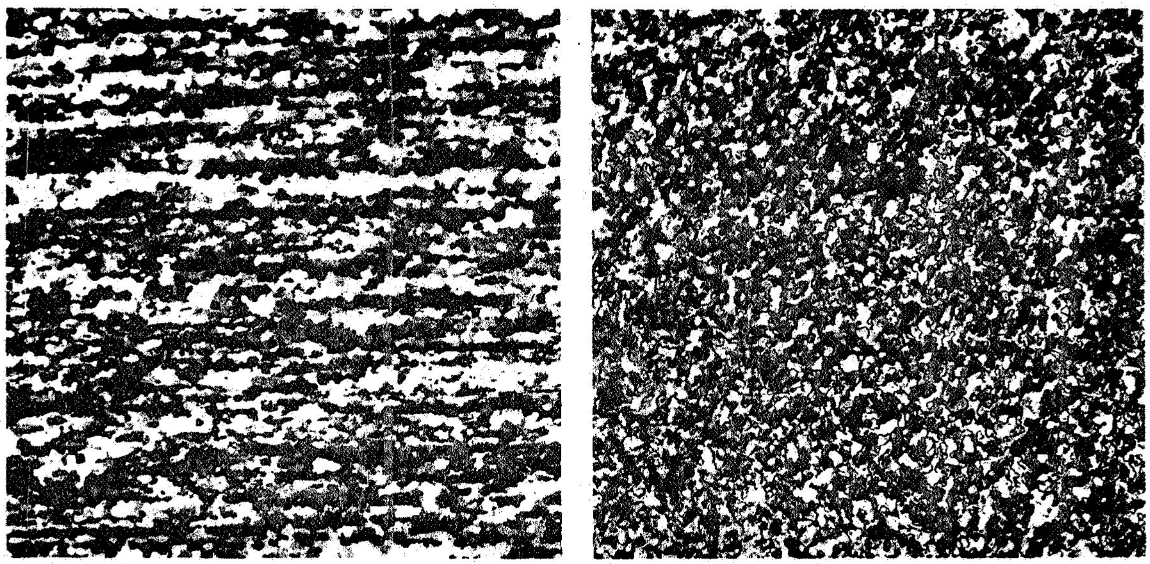
Figure 43 shows the microstructure of the Brush forgeable grade material in comparison with the Berylco XT-20 extruded material in transverse and longitudinal direction.

H. Twist-off Nuts

Since the maximum utilization temperature was increased to 800°F, 347 stainless steel in the annealed condition was used for the twist-off nuts. Standard machining practices were used in the fabrication of the nuts. The major problem encountered was the establishment of an optimum notch geometry for the twist-off portion of the nut. A preload of 30 percent to 40 percent of the ultimate strength was considered adequate for this fastener system. Hence, a notch geometry was established for the 5/16 diameter to permit the wrenched portion to shear off at a predetermined torque for the desired preload.

I. Established Method of Manufacture for Prestressed Fastener

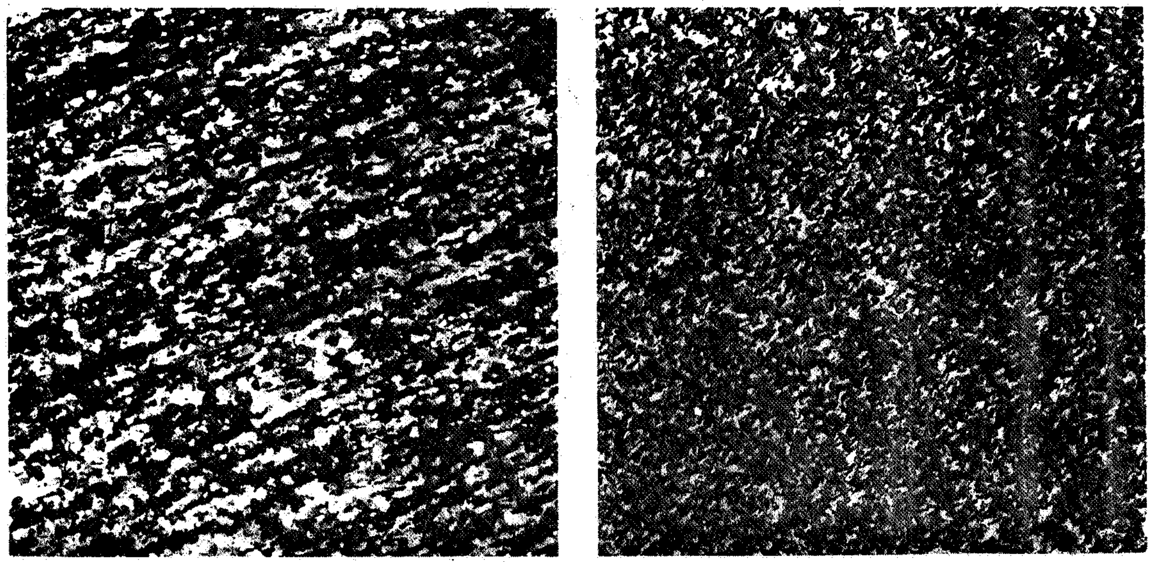
With the fastener configuration, tooling, and manufacturing studies completed, protruding and flush head point-drive bolts, and twist-off nuts were manufactured in the 5/16-24 diameter. Process of manufacture was established and fasteners were subsequently tested to determine if they would meet or exceed the target requirements. A representative photograph of the prestressed and blind fastener systems tested is presented in Figure 44.



Longitudinal Transverse

Unetched Surface
Magnification X100
Polarized Light

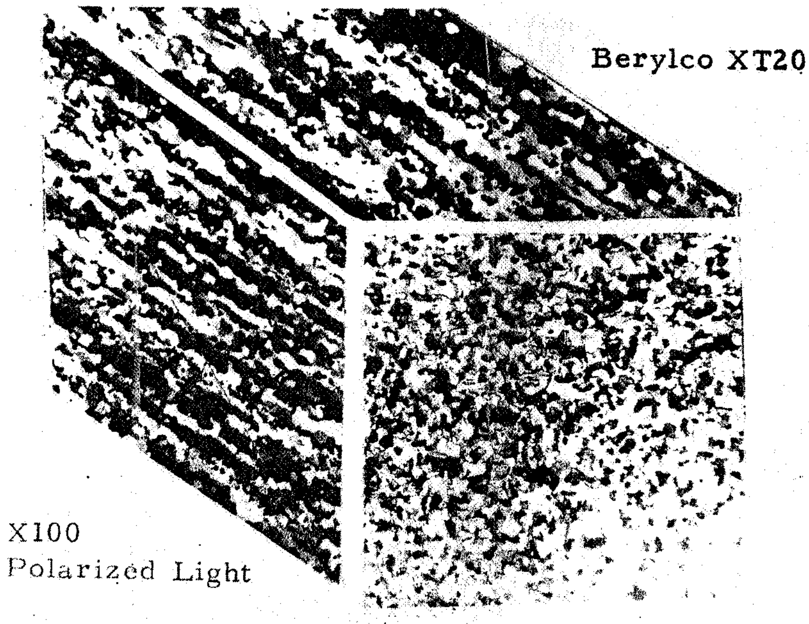
Figure 41. Photomicrostructure of "As-Received" Berylco XT-20 Material in the Longitudinal and Transverse Directions.



Longitudinal Transverse

Unetched Surface
Magnification X100
Polarized Light

Figure 42. Photomicrostructure of "As-Extruded" Berylco XT-20 Material in the Longitudinal and Transverse Directions.



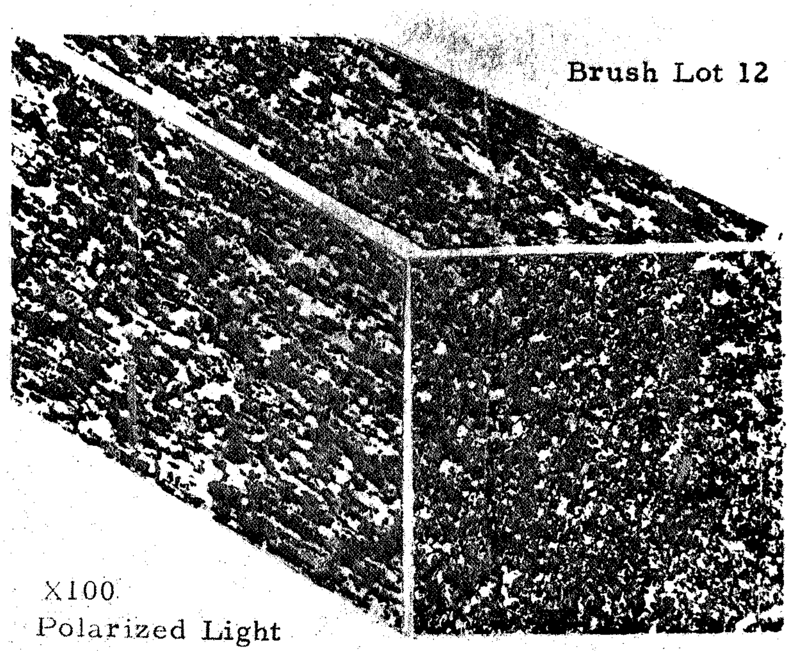
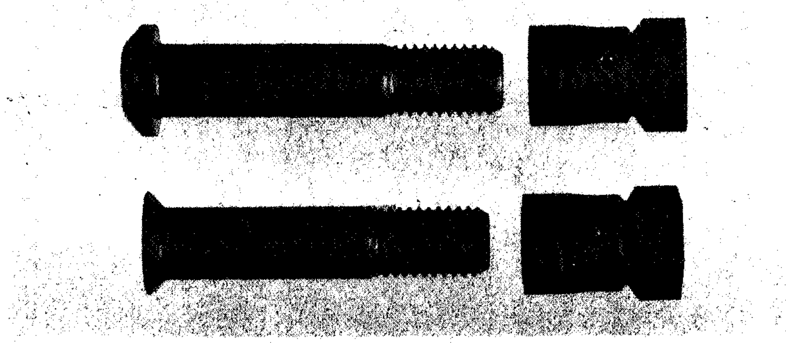
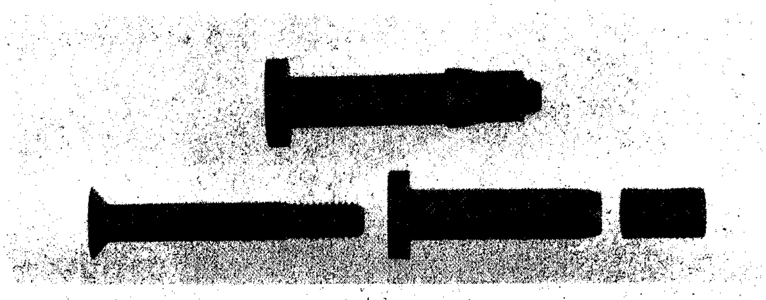


Figure 43. Composite Photomicrostructure of "As Extruded" Berylco XT-20 Material and "As-Received" Brush Forgeable Grade Material



Prestressed Fastener System



Blind Fastener System

Figure 44. Representative Photograph of Prestressed Fasteners and Blind Fasteners.

I. Established Method of Manufacture for Prestressed Fastener (continued)

The following process of manufacture was established for the point-drive bolts and twist-off nuts.

1. Point Drive Bolt

   a. Cut off and face to length
   b. Etch to extrusion diameter
   c. Fluorescent penetrant inspect and visual inspect at 40x magnification
   d. Forward extrude
   e. Rough machine head configuration
   f. Grind body and under head
   g. Form head and point
   h. Etch entire blank
   i. Fluorescent penetrant inspect and visual inspect at 40x magnification
   j. Grind thread roll diameter
   k. Etch thread roll diameter
   l. Roll threads
   m. Drill and broach hexagon recess
   n. Etch hexagon recess
   o. Fluorescent penetrant inspect and visual inspect at 40x magnification

2. Twist-off Nut

   a. Drill, face and counterbore
   b. Tap threads
   c. Form nut outer diameters
   d. Cut off
   e. Face and counterbore opposite end
   f. Grind breakneck on Threaded Mandrel

J. Blind Bolt Manufacturing Method

1. Manufacture of Beryllium Core Bolts

The manufacture of the beryllium core bolt did not necessitate the use of any new manufacturing process. All core bolts were produced from XT-20 material which was further extruded by SPS. Any problems associated with manufacturing these components were attributed to XT-20 material deficiences.

J. Blind Bolt Manufacturing Method (continued)

2. Manufacture of Beryllium Sleeves

The beryllium sleeves for the blind bolt were made of XT-20 material which was further extruded by SPS. The use of this SPS extruded material was discontinued since concentricity problems arose when it was necessary to turn and drill 3 inch extruded blanks. Delaminations, the cause of sleeve cracking during the etching cycle also resulted when SPS extruded material was used for the tapped sleeves.

Carbide tipped rifled drills, reported necessary for the deep drilling of beryllium material (Ref. 5) were not used to bore the beryllium sleeves. C-2 two fluted carbide drills were used successfully in drilling the deep holes in the center of the beryllium sleeves. Lathe turning speeds were approximately 1270 rpm for 9/64, 3/16, and 7/32 center holes. The most important factor, however, in the successful drilling of any beryllium sleeve employing a hand fed lathe operation is the competence of the lathe operator.

Tapping of beryllium sleeves resulted in a high rejection rate due to cracking and spalling in the threaded portion of the sleeves. Since the cracking problem associated with the tapping of the beryllium sleeves was extremely difficult to overcome it was decided to eliminate the sleeve tapping operation.

3. Manufacture of the Steel Collars

Since the collars were manufactured from stainless steel, normal steel manufacturing processes were employed.

K. Tooling

As noted from the previous discussion on manufacturing methods, standard tooling used for the manufacturing of steel fasteners was satisfactory. The development of new tooling was not required.

TABLE XV

MATERIALS SUBMITTED BY THE BERYLLIUM CORPORATION AND BRUSH BERYLLIUM COMPANY FOR INVESTIGATION OF FORGING CHARACTERISTICS
(Fastener Program for Contract NAS8-20158)

Lot No.	Type	Diameter, inches	Extrusion Reduction Ratio	Extrusion Temperature, °F
a. Brush QVM Extruded Rod				
4028		0.268	4.5:1	-
4033-1	N-50	0.268	28:1	1600
4033-4	N-50	0.268	28:1	1400
-	N-50 (a)	0.268	-	-
7886	Mounds Rod	0.268	(b)	(b)
-	Mounds Rod (a)	0.268	(b)	(b)
4002	-	0.268	-	-
4002	(a)	0.268	-	-
b. Berylco				
-	HP 20		Hot Pressed Block	
-	HPN 8		40:1	

(a) Stressed relieved at 1385°F
(b) Extrusion reduction ratios & temperatures considered proprietary information by Brush Beryllium Company

TABLE XVI

RESULTS OF HOT FORGING INVESTIGATION OF BERYLLIUM MATERIALS EVALUATED IN PHASES II & III (Fastener Program for Contract NAS8-20158)

Head Configuration for 1/4 inch Diameter Bolts

Spec. No.	Surface Condition	Inches Etched/ Surface	Head Configuration	Forging Temp. °F	Remarks
Brush SP 100-C					
1 to 6	Ground	-	Hex	1200 - 1800	Longitudinal
7	Etched (a)	0.005	Hex	1200	Cracks at Head
8	"	0.005	Hex	1300	and Point
9	"	0.005	Hex	1400	"
10	"	0.005	Hex	1500	"
11	"	0.010	Button	1450	"
Berylco PX-12					
1	Ground	-	Protruding	1425	Longitudinal
2	"	-	Protruding	1450	Cracks at Head
3	"	-	Protruding	1525	"
4	Etched (a)	0.005	Protruding	1000	"
5	"	0.005	Protruding	1250	"
6	"	0.005	Protruding	1450	"
7	Machined	-	Protruding	1450	"
8	Mach. & Etched (a)	0.002	Protruding	1450	"
9	Etched (a)	0.005	Hex	1450	"
Beryllium Metals Grade 3.0 Powder					
1	Ground	-	Protruding	1550	Longitudinal
2	"	-	Protruding	1650	Cracks at Head
3	"	-	Hex	1500	"
4	"	-	Button	1000	"
5	"	-	Button	1400	"
6	"	-	Button	1650	"
General Astrometals GB-2					
1	Machined	-	Protruding	1450	Longitudinal
2	"	-	Protruding	1550	Cracks at Head
3	Etched (a)	0.010	Button	1450	"
4	"	0.005	Hex	1450	"

(a) 100g chromic acid (anhydride)
77 ml phosphoric acid
10 ml concentrated sulphuric acid
50% by volume water

TABLE XVII

DOUBLE SHEAR PROPERTIES OF BERYLCO BERYLLIUM MATERIALS FORWARD EXTRUDED AT SPS LABORATORIES
(Fastener Program for Contract NAS8-20158)

Partially Extruded at 1100°F (50% Reduced)
Diameter Before Extrusion - 0.494 inches
After Extrusion - 0.350 inches
Machined and Etched to 0.312 inch diameter
Etched 0.004 inches per surface except where noted

Material	Ultimate Load, pounds	Ultimate Stress, psi (1)	Mode of Fracture
Hot Pressed Block (HP 20)	5,830	38,100	Brittle
Hot Pressed Block (HP 20)	5,900	38,600	Brittle
Extruded Bar	8,060	52,700	Brittle
Extruded Bar	9,730	63,600	Brittle
XT-20	11,400	74,600	Ductile
XT-20	11,400	74,600	Ductile
XT-20(a)	9,600	62,800	Brittle
XT-20(a)	9,500	62,100	Brittle
XT-20(a)	8,240	53,900	Brittle
XT-20(a)	9,900	64,700	Brittle
XT-20(b)	8,500	55,600	Brittle

(1) Stress calculated at Twice Nominal Diameter Area, 0.1530 square inches

(a) Etched 0.001 inches per surface
(b) Unetched - machined surface

TABLE XVIII

MECHANICAL PROPERTIES OF 5/16-24 POINT DRIVE BOLTS FABRICATED FROM FORWARD EXTRUDED BERYLCO XT-20 BERYLLIUM

(Fastener Program for Contract NAS8-20158)

Bolt Configuration - PDP16-10-24 (Protruding Head)
Forward Extruded at 1100°F
Bolt Diameter - 5/16-24 (55% thread height)

1. Tensile (tested with threaded bushing)

Ultimate Load, pounds	Ultimate Stress, psi (1)	Location of Failure
a. Threads in the unetched condition		
5,440	94,000	Head
4,600	79,700	Head
4,700	81,000	Head
b. Threads etched .001 inches per surface		
4,850	83,500	Thread
4,750	81,800	Head

2. Double Shear

Ultimate Load, pounds	Ultimate Stress, psi (2)
12,400	80,900
13,000	84,800

(1) Stress calculated at Tensile Stress Area of 0.05805 square inches
(2) Stress calculated at Twice Nominal Diameter Area, 0.1530 square inches

SECTION VII

FABRICATION AND TESTING

With the establishment of the material, fastener configuration and process of manufacture, the fabrication and testing of a production size lot in both the protruding head and flush head configuration were initiated.

This phase of the program was run only for the prestressed fastener system. Because of the difficulties encountered in the development of the blind fastener system, it was agreed that feasibility of design and manufacture, and sufficient test data to support the final design would be adequate.

A. Fabrication

The selected material, Berylco XT-20 was fabricated into the bolt configurations shown in Figures 4 and 5 listed in Section V. Companion twist-off nuts of annealed 347 stainless steel were made in accordance with the engineering drawing illustrated in Figure 45.

The diameters, grip lengths and quantities manufactured were as follows:

Protruding Head Prestressed Fastener Assemblies

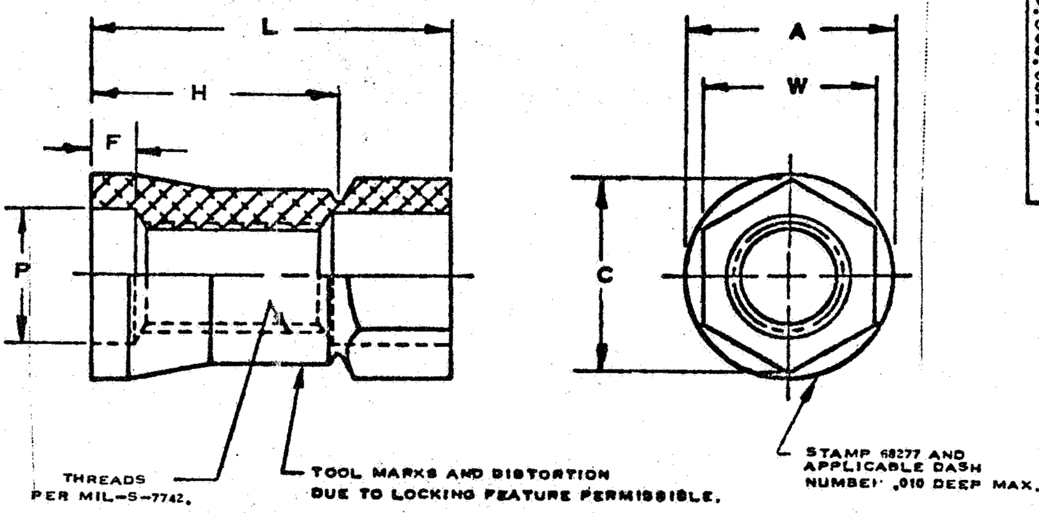
Item No.	Diameter	Grip Length	Quantity
1	#10-32	1/8"	700
2	#10-32	3/16"	200
3	#10-32	1/4"	50
4	#10-32	5/16"	200
5	#10-32	3 /8"	100
6	#10-32	7/16"	75
7	#10-32	9/16"	157
8	1/4-28	3/4"	157
9	5/16-24	15/16"	157

STANDARD PRESSED STEEL COMPANY
PRECISION FASTENER DIVISION

SHEET 1 OF 2

DRAWING NUMBER SD.300.68277

REVISION



PART NUMBER	(1) THREADS MODIFIED	A MAX.	C MIN.	F ±.010	H REF.	L	P ±.005	W	(2) X	AXIAL TENSILE STRENGTH LBS. MIN.	INSTALLATION TORQUE IN.-LB.
68277-6	.190-32UNF-3B	.310	.347	.101	.280	.446	.210	.313 .305	.005	1,410	6 - 11
68277-8	.250-28UNF-3B	.342	.383	.107	.349	.541	.270	.345 .336	.005	2,560	18 - 23
68277-10	.312-24UNF-3B	.435	.491	.112	.439	.661	.334	.439 .430	.005	4,100	35 - 40

PART NUMBER	TORQUE OFF IN. LBS.	(3) WEIGHT MAX. LBS./100
68277-6	15 - 25	.11
68277-8	25 - 35	.22
68277-10	65 - 80	.48

(1) THREADS: BEFORE LUBRICATION PER SPS T-147 (MIL-S-7742 55% THREAD HEIGHT).
(2) BEARING SQUARENESS: BEARING SURFACE TO BE SQUARE WITH PITCH DIAMETER WITHIN X T.I.R.
(3) MAXIMUM WEIGHT REFERS TO PORTION OF NUT BY DIMENSION H REFERENCE.

TOLERANCES: AND UNLESS OTHERWISE NOTED REF. 65334

STANDARDS AND SPECIFICATIONS	TITLE	DRAWN BY W.J.S. DATE 9-27-66
	NUT SELF-LOCKING, TORQUE, 347 STAINLESS STEEL (ANNEALED) 800°F 1/16 GRIP VARIATION	APPROVED DATE 9-27-66
CUSTODIAN: JENKINTOWN, PA.		PART NUMBER 68277

Figure 45. Engineering Drawing for 347 Stainless Steel Twist-off Nut.

STANDARD PRESSED STEEL CO.
PRECISION FASTENER DIVISION

SHEET 2 OF 2

DRAWING NUMBER SD.300.68277

REVISION

NOTES:

MATERIAL ANNEALED 347 STAINLESS STEEL.

LUBRICANT DRY FILM LUBRICANT SPS-K4.

LOCKING TORQUE: NUT PROVIDE PREVAILING TORQUE TO ONE APPLICATION.

BREAK SHARP CORNERS.

DIMENSIONS TO BE MET PRIOR TO LUBRICANT.

DIMENSIONS IN INCHES UNLESS SPECIFIED OTHERWISE.

SURFACE TEXTURE: ASA-B46, UNLESS OTHERWISE SPECIFIED THE SURFACE TEXTURE SHALL NOT EXCEED 125 MICROINCHES.

DESIGN AND USAGE LIMITATIONS: THESE NUTS ARE DESIGNED TO BE USED WITH BOLTS AND SCREWS WITH A SHEAR STRENGTH OF 65 KSI. THE NUTS ARE TO BE USED ON CLASS 3A EXTERNAL THREADS WITHIN THE LIMITATIONS OF MS 33588.

PART NUMBER: SPS PART NUMBER CONSISTS OF BASIC PART NUMBER PLUS APPLICABLE DASH NUMBER. DASH NUMBER DESIGNATES THREAD SIZE.

EXAMPLE: 68227-6 .250-28 UNF-3B MOD.

THIS NUT FOR USE ON BERYLLUM BOLTS.

889-1 REV. 868

Figure 45. (continued)

A. Fabrication (continued)

100° Flush Head Prestressed Fastener Assemblies

Item No.	Diameter	Grip Length	Quantity
10	#10-32	9/16"	100
11	1/4-28	3/4"	100
12	5/16-24	15/16"	100

From Lots 7 through 12, fifty-seven assemblies from each lot were used for the test program. Upon completion of final inspection the remaining assemblies were sent to the Project Monitor at the George C. Marshall Space Flight Center.

1. Discussion

Many problems were encountered during the manufacture of the beryllium point drive bolt. Principal among these were:

Severe cracking during the extrusion process
Cracks in the thread area after thread rolling.

Although cracks were noted at the point of extruded blanks during the developmental program conducted in Phase II, the cracks never extended more than one-sixteenth inch along the longitudinal axis. This section was subsequently cropped off and the blanks were manufactured into finished fasteners. However, during the fabrication of the production size lot, visual examinations revealed cracks that extended into the head area. Consequently, where this condition was noted, the blanks were rejected and considered scrap. The ultimate yield of finished fasteners including those for the test program was 40 percent of the total required. And the majority of these exhibited cracks at the thread crest.

During the course of this program, fabrication was temporarily halted. A program was conducted to determine whether the material and/or processing was the cause of thread cracking and inconsistent thread strength noted in preliminary tensile tests. Areas investigated were stress relieving prior to thread rolling and variations in the thread

A 1. Discussion (continued)

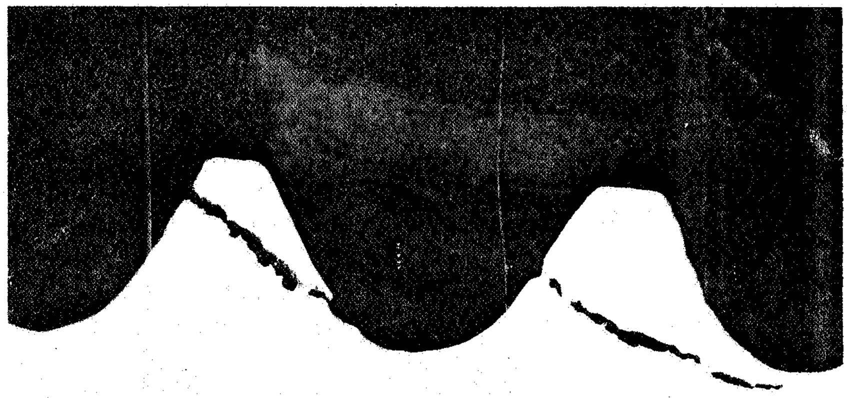
rolling process. In addition, studs were made from four different material heats, procured for the program, to determine if there were any significant disparities from one heat to another. The results of the evaluation indicated the following:

a. Cracks at the thread crest could not be eliminated either by stress relieving prior to thread rolling or by variations in the thread rolling process. In some cases crack free threads were noted where the threads were not fully packed but these results could not be reproduced. The photo-microstructure of a 1/4-28 thread with cracked threads is shown in Figure 46. Note, however, the absence of cracks in the photo microstructure of a 1/4-28 thread rolled on the Brush forgeable grade material in Figure 47. These threads were rolled employing the same process as the XT-20 material.

b. Tensile properties of forward extruded XT-20 bolts with rolled threads were very inconsistent. This could be attributed to the depth of the cracks in the thread area. Threads with cracks not extending below the pitch diameter would probably have higher strength than threads with cracks extending below the pitch diameter. Thus the wide scatter in tensile strength which ranged from 40,000 psi to 90,000 psi.

c. There did not appear to be any significant difference from one heat of material to another. Studs fabricated from four heats of XT-20 material exhibited the typical cracks on the thread crest as shown in Figure 48.

d. It can be concluded that from recent work conducted with Brush Forgeable grade material that the processing was not the cause of the thread cracking.



Bright Field
Mag. X25

Figure 46. Photomicrostructure at the Thread Area of a 1/4-28 Thread Rolled on Berylco XT-20 Material

Bright Field
Mag. X25

Figure 47. Photomicrostructure at the Thread Area of a 1/4-28 Thread Rolled on Brush Forgeable Grade Material

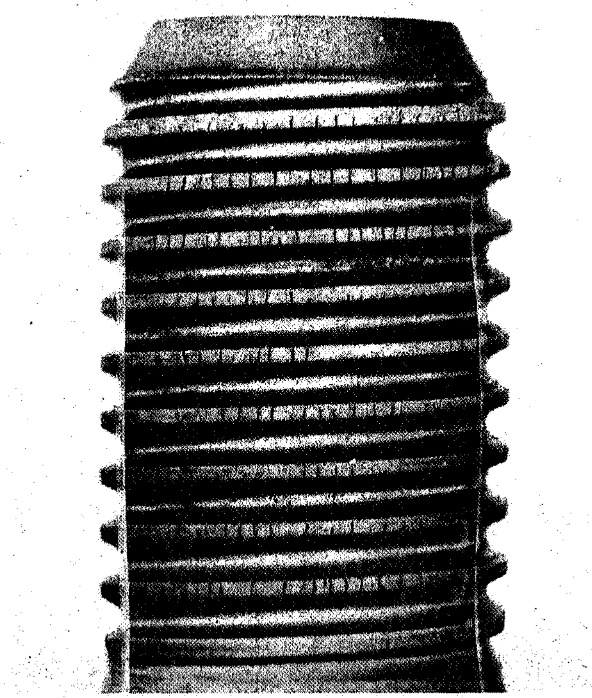


Figure 48. Photomacrograph of Rolled Threads on Berylco XT-20 Material

Note the cracks at the thread crest. This was typical for threads rolled on the XT-20 material

A. 1. Discussion (continued)

The Project Monitor was informed of the manufacturing difficulties and the inconsistent results of the preliminary tensile tests. A decision was made that manufacturing be resumed and that fasteners to be sent to Marshall Space Flight Center be supplied on a best effort basis as long as shear properties determined in the test program remained consistent.

B. Design

Additional development work was run in this phase for the #10 and 1/4 inch diameter prestressed fasteners. The overall dimensions of the twist-off nut were decreased below those of similar aluminum and steel twist-off nuts. They were considered within design allowables to effect maximum weight reduction.

Installation torque values which are listed in Figure 45 are on the low side as compared to aluminum twist-off nuts used in conjunction with steel point drive bolts. Design parameters necessitated these torque values since the minimum torsional yield strength of standard hexagon wrenches was slightly higher than the maximum installation torque listed. The selected coating for these nuts was SPS K4 lubricant which is an organic-inorganic molybdenum disulphide dry film lubricant. This lubricant was developed for exposure to temperatures from -300°F to 1400°F. It is reported by the Bel-Ray Company, Inc. of Farmingdale, New Jersey to be an excellent coating for surfaces exposed to liquid oxygen.

C. Testing

The test program for the prestressed fastener system is shown in Figure 49. The scope of the program was considered comprehensive for the determination of the beryllium prestressed fastener properties for use in the Saturn V thrust structure.

TEST PROGRAM
PRESTRESSED FASTENERS-PHASE IV

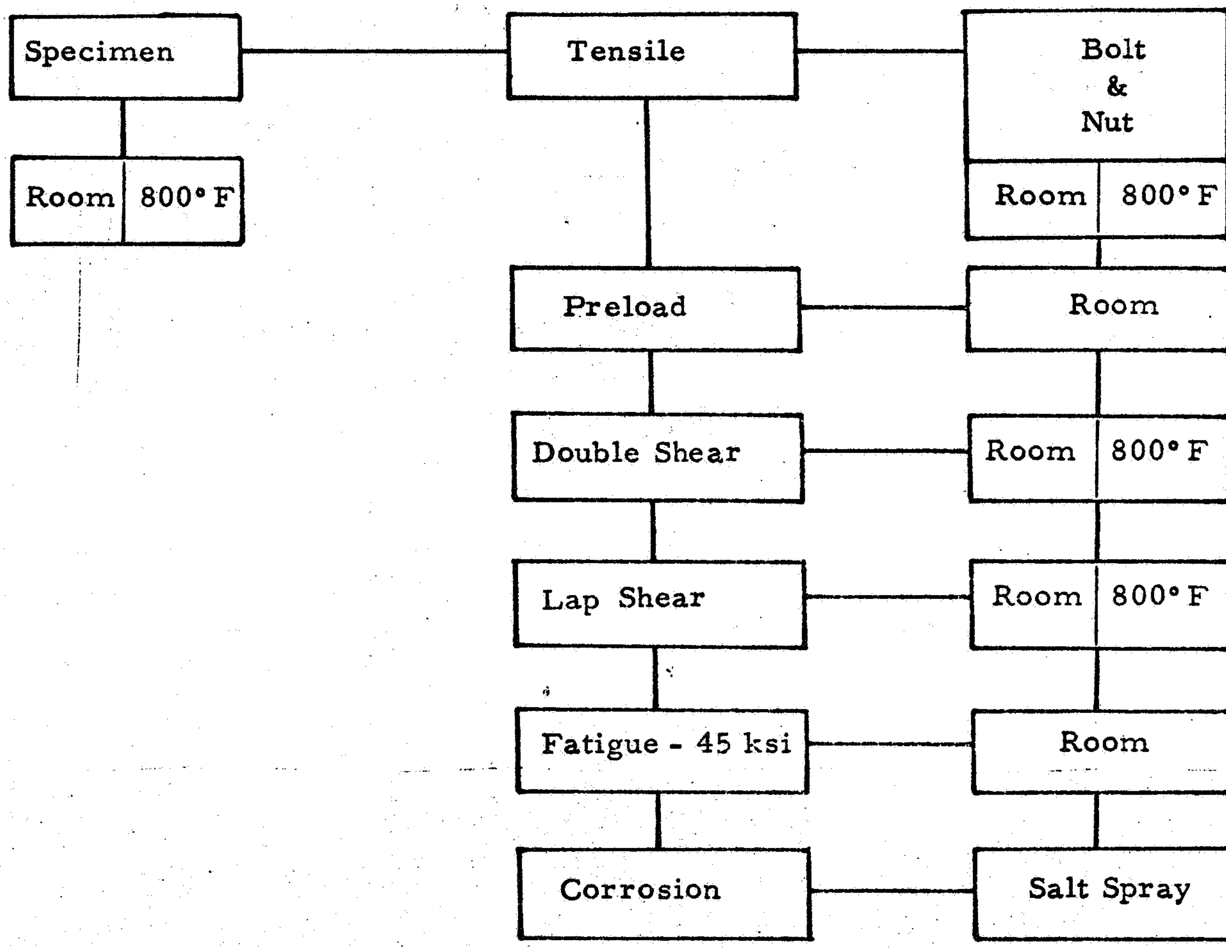


Figure 49. Test Program for Prestressed Fasteners Tested in Phase IV

C. Testing (continued)

1. Tensile

a. Fastener System

Ultimate tensile strength and preload (clamping force) were determined for installed fastener systems. Determination of preload was conducted at room temperature.

b. Material

To evaluate the base material from which the extruded bolts were fabricated, standard 0.113 inch tensile test specimens were machined and etched from finished bolts and tested at the same temperatures as the bolts.

2. Shear

Since the fasteners evaluated in the program are designed primarily for shear application, determination of fastener shear properties was axiomatic. In addition, beryllium joint strengths and beryllium-aluminum joint strengths were determined. Comparison of the lap joint versus the butt joint was conducted.

3. Tension-Tension-Fatigue

Fatigue life at a maximum stress of 45,000 psi and an R ratio of 0.1 was determined.

4. Corrosion

Corrosion resistance properties in an accelerated salt spray atmosphere were determined.

D. Test Procedures and Equipment

1. Tensile

a. Specimens

Tensile tests of specimens (Figures 50 & 51) were conducted in accordance with ASTM E8-65T designation on Tinius Olsen Universal Testing Machines employing a uniform loading rate of 0.005 inch/inch/minute.

Material yield strengths were determined by the 0.2 per cent offset method described in ASTM designation E8-65T. A Tinius Olsen S-3 extensometer attached to the test specimen was used for plotting load extension curves and subsequent determination of room temperature yield strengths.

At 800°F, an alternate method as shown in Figure 52 was used for plotting the stress-strain curves for determination of yield strength.

b. Fastener Assemblies

Tensile tests of installed fastener assemblies were conducted in accordance with ATC Report Number ARTC-33, dated March 1964. Deviation from this procedure was in the determination of preload or clamping force at room temperature. This was determined employing the fixture shown in Figure 53. Prior to assembly, shims were inserted at the joint surfaces. The fasteners were then installed and tested in tension on the Universal Testing Machine. While the load was being applied, a constant force of approximately five pounds was exerted on the shims in a direction perpendicular to the longitudinal axis of the fastener. The load at which initial movement of the shims was noted was recorded and determined as the preload or clamping force.

D. Test Procedures and Equipment (continued)

c. Specimen Preparation

1. Round Bar Tensile Specimens

The round bar tensile specimens were prepared as follows:

a. Rough machined undercut section from finished bolts 0.048 inch oversize.

b. Finished machined undercut in the following sequence:

1st Cut	- removed 0.010 inch/surface
2nd Cut	- removed 0.005 inch/surface
3rd Cut	- removed 0.003 inch/surface
4th Cut	- removed 0.001 inch/surface

c. Removed 0.0005 to 0.001 inch/surface by polishing using abrasive paper with grit No's. 240 through 600.

d. Removed a minimum of 0.003 inch/surface by chemically etching.

2. Flat Sheet Tensile Specimens

The flat sheet tensile specimens were prepared as follows:

a. Rough cut blanks from sheet with a band saw.

b. Rough machined undercut on milling machine 0.048 inch oversize.

c. Drilled pin holes 0.006 inch undersize

d. Finished machined, polished and etched in the same sequence as that for the round bar specimens.

D. Test Procedures and Equipment (continued)

2. Shear

a. Double Shear

Double shear tests at room temperature were conducted using the fixtures shown in Figure 54. The tests were run in accordance with ATC Report Number ARTC-33, dated March, 1964.

At 800°F, the fixtures shown in Figure 55 were used. A uniform loading rate of 100,000 psi per minute was used for these tests.

b. Lap Shear

Lap shear tests of both lap joints and butt joints were run at room and 800°F temperatures using various t/d ratios (sheet thickness/bolt diameter). These ratios were selected by the Project Monitor and inserted in the test program. They were:

	Beryllium Lap Joint	Beryllium Butt Joint	Beryllium-Alum. Butt Joint
#10 Diameter			
Protruding Head	0.526	0.526	
Flush Head	0.526	—	1.05
1/4" Diameter			
Protruding Head	0.400	0.400	
Flush Head	0.400		0.800
5/16" Diameter			
Protruding Head			0.642
Flush Head			0.642

Figures 56 through 61 show the sheet specimen configurations for the lap and butt joint shear tests conducted in the test program. In Figures 62, 63 and 64, the test set-up for the beryllium lap joint, beryllium butt joint and beryllium-aluminum butt joint shear tests are illustrated.

D. - 2. b. Lap Shear (continued)

Joint offset yield strengths were determined for all tests. These tests were conducted in accordance with ATC Report Number ARTC-33, Fastener Lap Joint Test Procedure, paragraph 5.0. This report states that for bolts and non-hole filling fasteners a permanent set offset yield strength should be calculated at 4 percent of the gage length or 0.012 inches whichever is greater. However, because of the brittle nature of beryllium at room temperature, joint offset yield strength was calculated and recorded every 0.002 inches starting at 0.004 inches. The load extensometer used for determining the joint yield strength is illustrated in Figure 65. This extensometer in conjunction with an X Y recorder proved very satifactory for plotting load extension curves, particularly at the elevated temperature of 800°F. Gage lengths employed were:

2.0 inches for #10 diameter fasteners
4.0 inches for 1/4 inch and 5/16 inch diameter fastener

3. Elevated Temperature Tests

Elevated temperature tests at 800°F were run employing an infra-red furnace in conjunction with a Leeds and Northrup Speedomax Temperature Controller converted for use with the infra-red furnace using a Series 60 Controller. Temperature measurements were obtained using a minimum of two Chromel-Alumel thermocouples attached to the test specimens. Controller was checked with a Leeds and Northrup Portable Precision Potentiometer prior to each test. Test temperature was held for 15 to 30 minutes before the tests were initiated.

4. Tension-Tension-Fatigue

Tension-tension fatigue tests were run on a 5,000 pound Krouse Fatigue Machine. This is a direct loading machine which uses an eccentric cam for setting the desired loads. Rate of speed for this machine was approximately 1650 cycles per minute. Alignment was checked to insure a

D. 4. Tension-Tension-Fatigue (continued)

uniaxial set up so that bending would not cause premature failures.

In all cases, the minimum load was ten percent of the maximum load. Electronic load measuring equipment insured that both the minimum and maximum load were within plus or minus two percent.

5. Corrosion Resistance

Corrosion resistance properties of installed fasteners were investigated. For the investigation, fasteners in the following condition were completely installed in a machined and etched hot pressed beryllium block;

a. Etched beryllium bolt and uncoated 347 stainless steel nut.

b. Etched beryllium bolt and coated (M_oS_2) 347 stainless steel nut.

c. Etched beryllium bolt and etched beryllium nut.

The assembly was subjected to an accelerated salt spray environmental test for 72 hours. The test was conducted in accordance with Federal Test Method Standard 151, Method 811.

E. Results and Discussion

The results of the test program are tabulated in Tables XVIII through XXIII.

1. Tensile

As expected, cracks in the thread area had a significant effect on the tensile properties of installed fasteners. Tensile strengths ranged from 53,600 psi to 97,000 psi. In some cases, particularly for the #10-32 diameter assemblies, bolt threads failed during installation and seating of the twist-off nuts.

E. 1. Tensile (continued)

It should be noted that at the elevated temperature of 800°F tensile strengths were fairly consistent. The majority of failures occurred at the head to shank fillet area. In addition, fastener strength calculated at the tensile stress area was equivalent to the material strength which would indicate that the beryllium material was not notch sensitive at 800°F.

2. Double Shear

Double shear properties at room temperature exceeded the target requirements of the contract. For the three diameters tested, shear strength exceeded 65,000 psi.

3. Lap and Butt Joint Shear

Of particular interest were the results of the lap and butt joint shear tests. It would be conceived from a design standpoint, that the butt joint would be the stronger of the two because of the minimum bending stresses introduced during axial loading. This was not the case for the beryllium joints. A graphic representation of the t/d ratio versus the joint strength as plotted in Figure 66 shows that the lap joint was significantly stronger than the butt joint. At t/d ratios of 0.400 and 0.526, lap joint strength was approximately 100 percent higher than the butt joint strength at room temperature. A logical explanation for this higher strength is not known at the present time. Distribution of the joint tests is tabulated in Table XXV; and the results of the various joint tests are summarized in Tables XXVI through XXX. The results are tabulated using the single shear values calculated on the cross sectional area of the nominal fastener diameter.

Brittle tension failures were noted for all tests at room temperature. (Figure 67) Conversely at 800°F, shear failure of the center section resulted in the butt joint test and shear failure of the fasteners resulted in the lap joint tests. (Figure 68) Typical joint load curves from actual tests are shown in the appendix.

4. Tension-Tension Fatigue

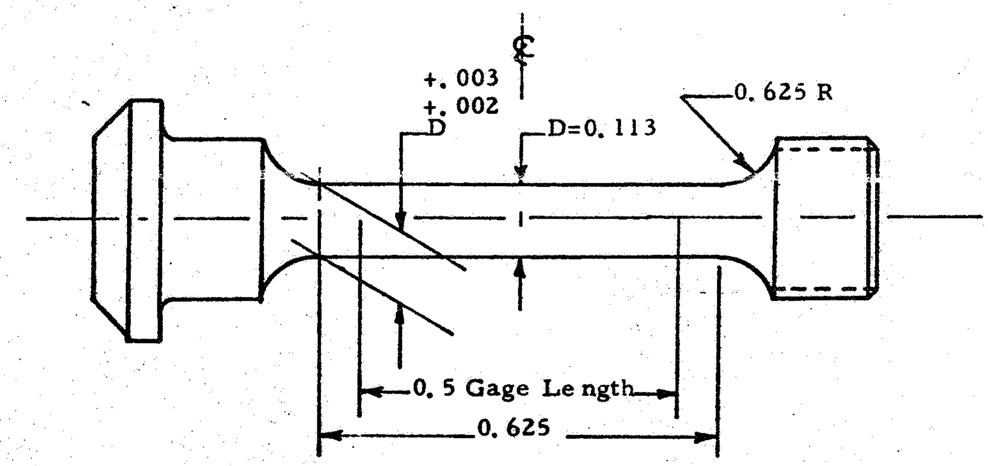
Tension-tension fatigue properties were drastically affected by the cracked threads. Fatigue life ranged anywhere from 16,000 cycles to 7,000,000 cycles at a maximum stress of 45,000 psi with R ratio of 0.1. It would be expected, however, that beryllium bolts of equivalent strength and tested with annealed stainless steel nuts would meet the endurance limit of 1×10^6 cycles at a 45,000 psi maximum stress. This would be dependent upon imperfect surfaces being removed prior to testing.

5. Corrosion Resistance

The corrosion resistance properties of beryllium with etched surfaces would be similar to aluminum material with untreated surfaces. Severe corrosion and pitting were noted after 24 hours in an accelerated salt spray environment. Evidently, a surface treatment such as black anodizing recommended by the Project Monitor would be required for maximum protection. Figure 69 shows prestressed fasteners installed in a beryllium hot pressed block which were subjected to the accelerated spray environment for 72 hours. Although stress corrosion was not noted, a more comprehensive program would have to be run to determine whether this possibility exists.

In summarizing the results, valuable information and experience were gained in the fabrication and testing technology for beryllium fasteners. However, the finished fastener produced for this contract would not be acceptable by Standard Pressed Steel Co. standards for high reliability fasteners. This primarily is due to the input base material and the forward extruding process.

REVISION AND DATE



NOTE:

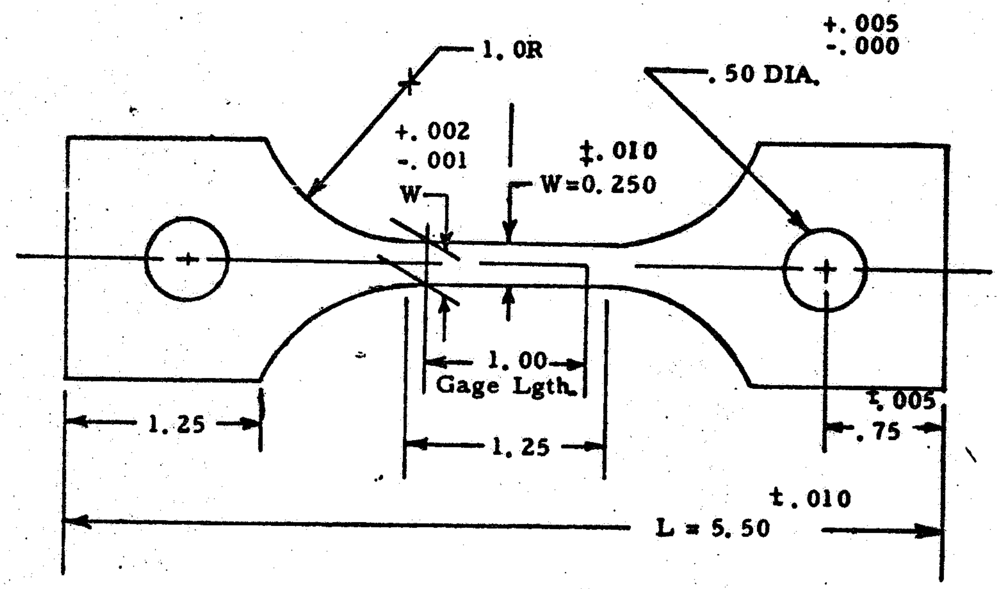
1. ETCH TO FINISH DIMENSIONS-.003-INCHES MINIMUM SURFACE REMOVAL
2. PITCH DIAMETER AND GAGE DIAMETER TO BE CONCENTRIC WITHIN .002 T.I.R.
3. BEARING SURFACE OF HEAD TO BE SQUARE WITH PITCH DIAMETER WITHIN .002 T.I.R

FIGURE 50.
TENSILE TEST SPECIMEN
FOR CONTRACT NAS8-20158

TOLERANCE UNLESS SPECIFIED	SPS LABORATORIES STANDARD PRESSED STEEL CO., JENKINTOWN, PA., 19046			
FRACT.:	MATL. BERYLLIUM		HEAT TREAT	
DEC.:	SCALE 4:1	NO. REQD	ASSY. DWG.	PARTS LIST
ANGLES:	DRAWN BY J. J. G.		DWG. NO.	
SURF. FIN. ✓	DATE			

1560

REVISION AND DATE



NOTE:
1. Etch to finish dimensions - . 003-. 004 inches minimum surface removal
2. Longitudinal centerline of pin holes and gage section to coincide within . 001 inches

FIGURE 51.
TENSION TEST SHEET SPECIMEN
FOR BERYLLIUM

TOLERANCE UNLESS SPECIFIED
FRACT. ±
DEC. ±
ANGLES ±
SURF. FIN. ✓

SPS LABORATORIES
STANDARD PRESSED STEEL CO., JENKINTOWN, PA., 19046

MATL.
HEAT TREAT
SCALE 1:1
DRAWN BY J. J. G.
DATE 6-7-67
NO. REQD
ASSY. DWG.
PARTS LIST
DWG. NO.

1560

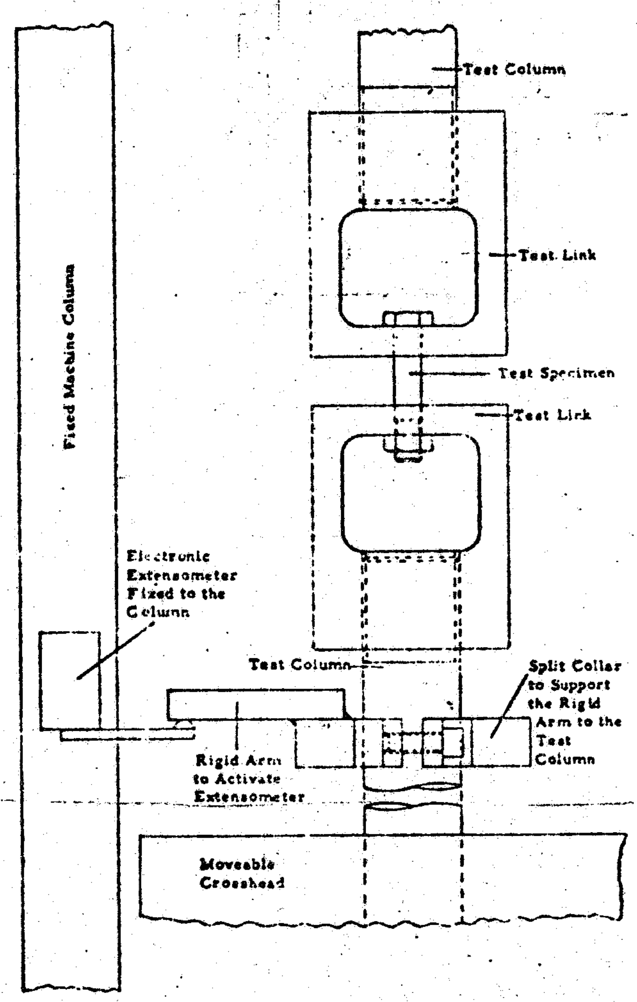


Figure 52. Alternate Stress-Strain Plotting Method for Elevated Temperatures.

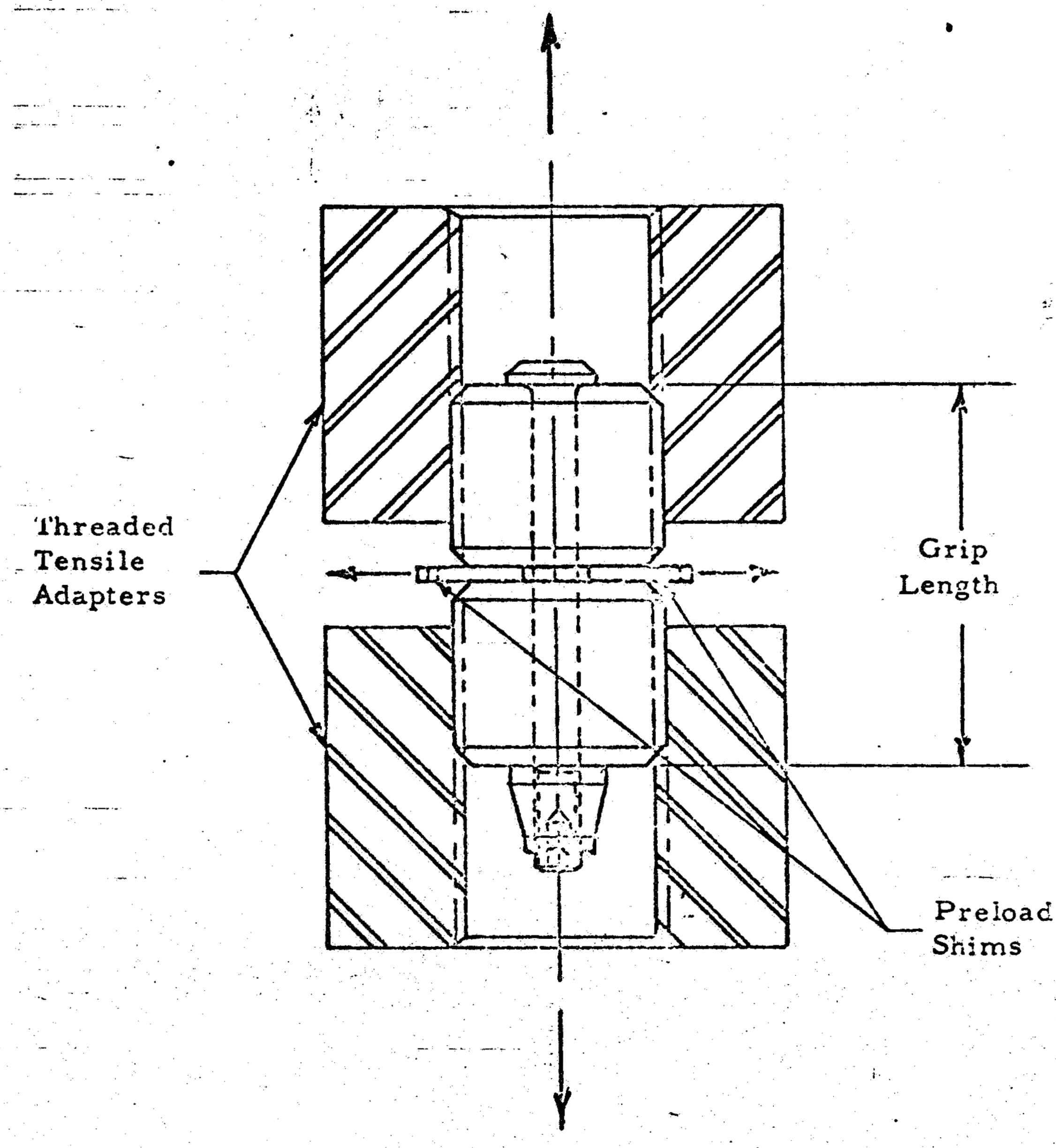
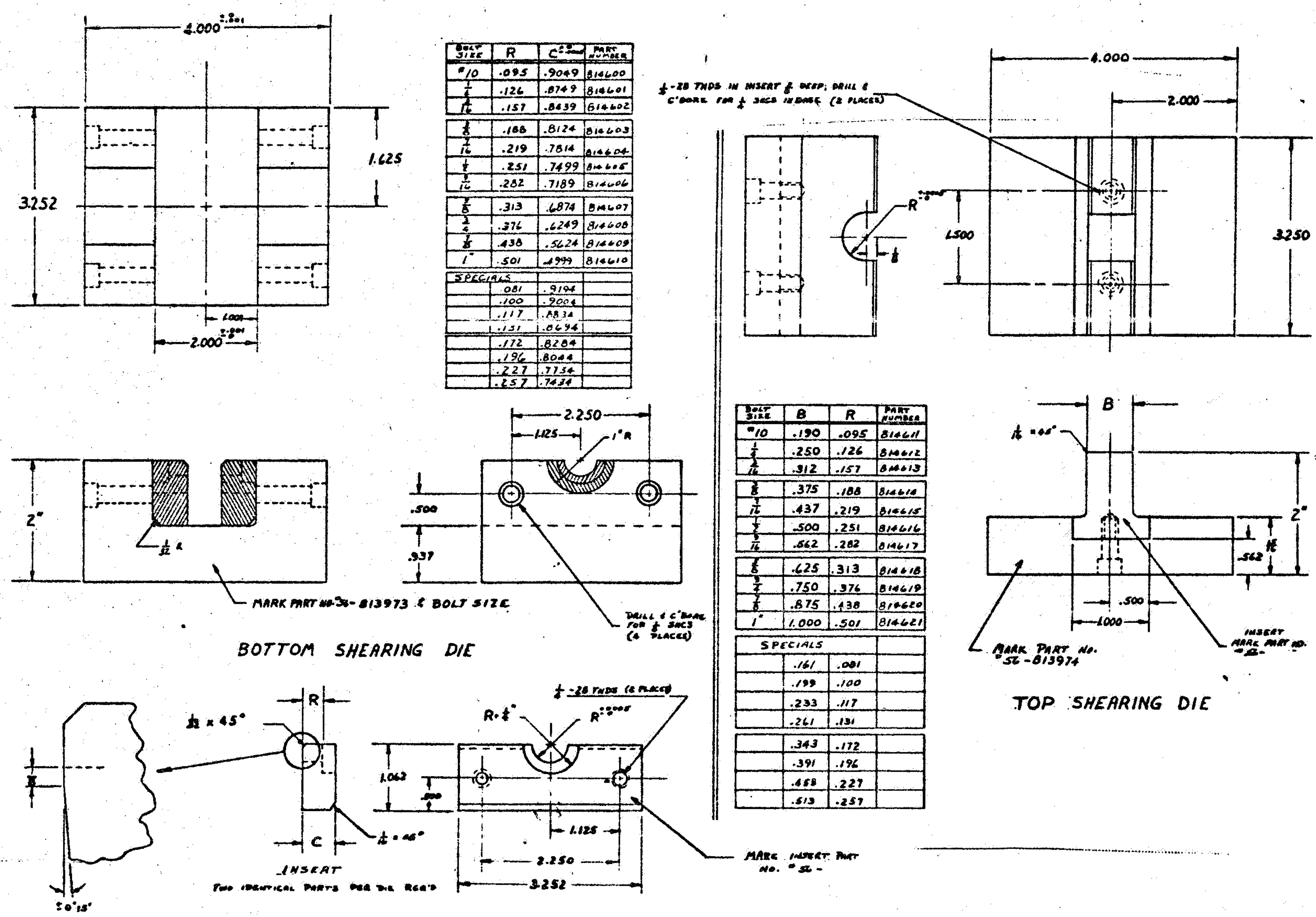


Figure 53. Fixture Setup for Preload and Tensile Testing Point Drive Fasteners and Blind Fasteners



BOLT SIZE	R	C	PART NUMBER
#10	.095	.9049	814600
1/4	.126	.8749	814601
5/16	.157	.8439	814602
3/8	.188	.8124	814603
7/16	.219	.7814	814604
1/2	.251	.7499	814605
9/16	.282	.7189	814606
5/8	.313	.6874	814607
3/4	.376	.6249	814608
7/8	.438	.5624	814609
1"	.501	.4999	814610
SPECIALS			
	.081	.9194	
	.100	.9004	
	.117	.8834	
	.131	.8694	
	.172	.8284	
	.196	.8044	
	.227	.7734	
	.257	.7434	

BOLT SIZE	B	R	PART NUMBER
#10	.190	.095	814611
1/4	.250	.126	814612
5/16	.312	.157	814613
3/8	.375	.188	814614
7/16	.437	.219	814615
1/2	.500	.251	814616
9/16	.562	.282	814617
5/8	.625	.313	814618
3/4	.750	.376	814619
7/8	.875	.438	814620
1"	1.000	.501	814621
SPECIALS			
	.161	.081	
	.199	.100	
	.233	.117	
	.261	.131	
	.343	.172	
	.391	.196	
	.458	.227	
	.513	.257	

Figure 54. Test Fixture for Double Shear Test

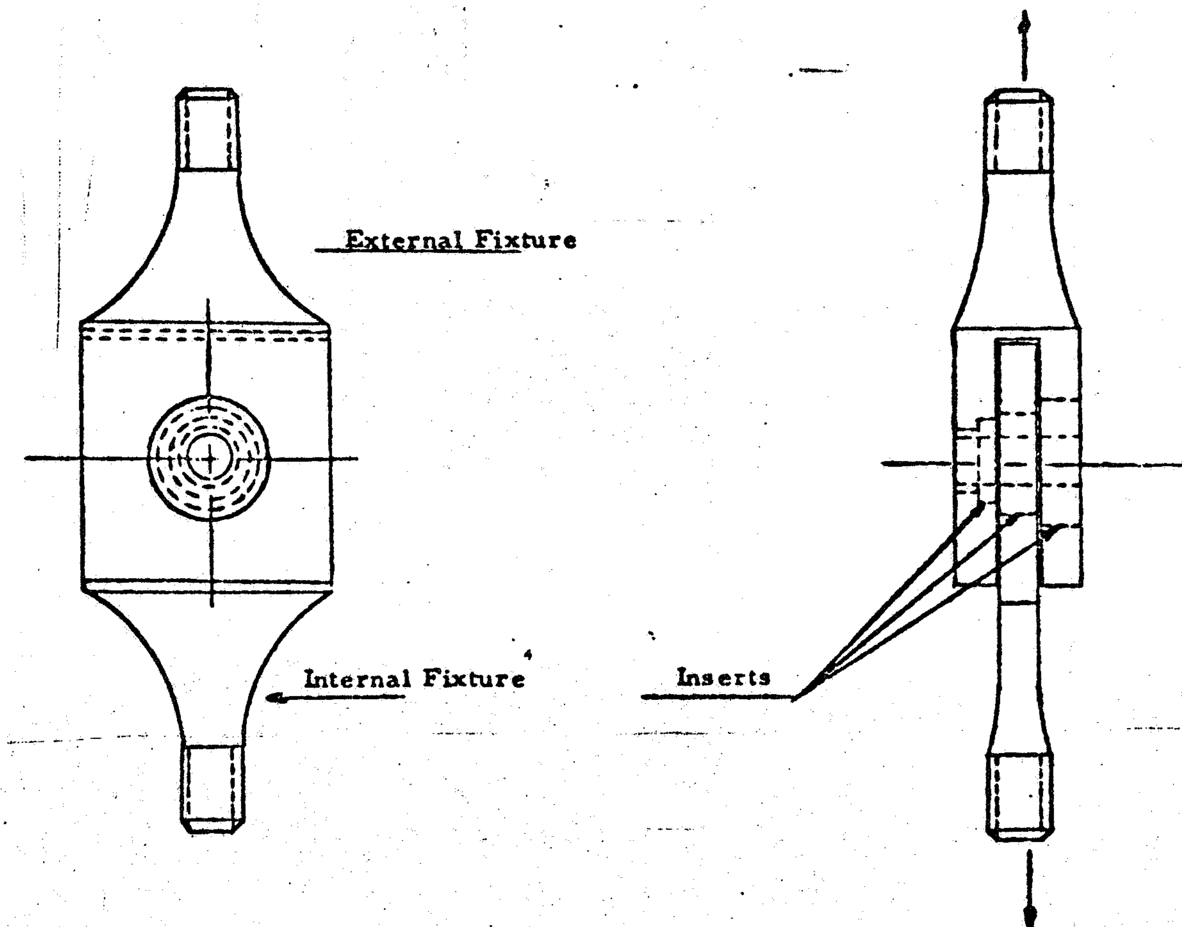
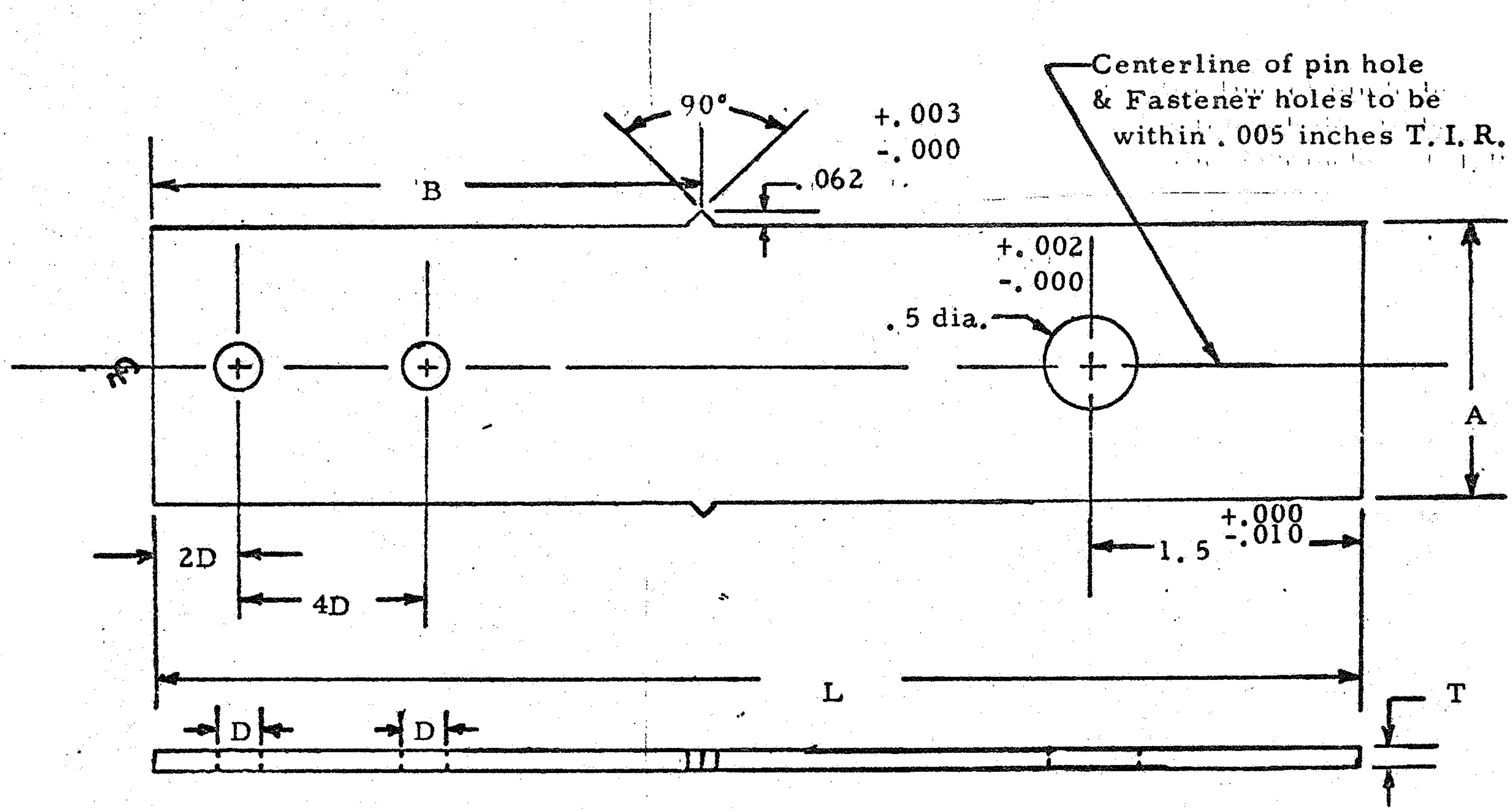


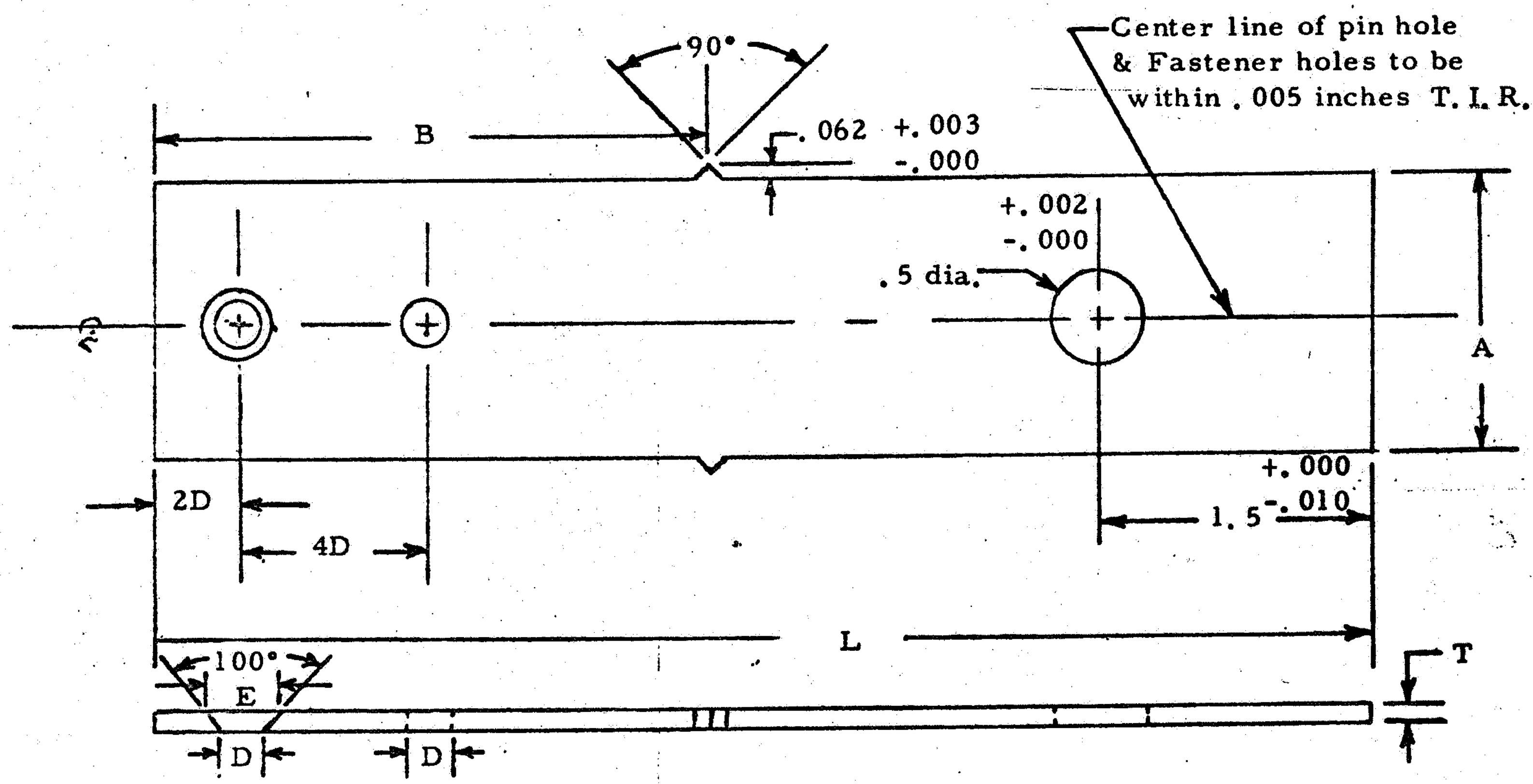
Figure 55. Cryogenic and Elevated Temperature Double Shear Fixtures



ITEM NO.	$A^{+}_{-}.010$	$B^{+}_{-}.002$	$D^{+.002}_{-.000}$	$L^{+}_{-}.010$	$T^{+}_{-}.001$
1	1.500	1.780	.190	6.625	.100
2	1.875	3.000	.250	6.625	.100

NOTE: 1. Each set must be machined, drilled and etched together.
2. Etch to finish dimensions - minimum of .002 per inches surface.
3. All dimensions in inches.

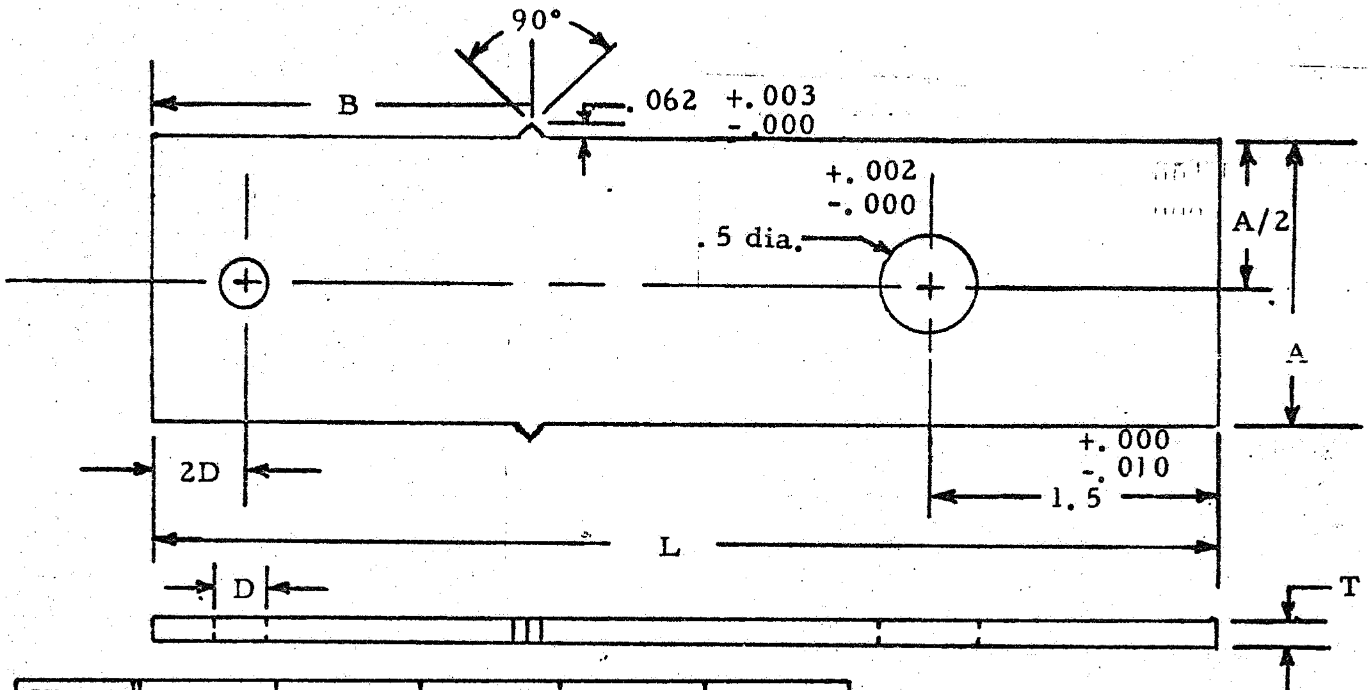
Figure 56 Beryllium Lap Joint Specimen for Protruding Head Bolts.



ITEM NO.	A ±.010	B ±.002	D +.002 -.000	E ±.005	L ±.010	T ±.001
1	1.500	1.780	.190	.280	6.625	.100
2	1.875	3.000	.250	.372	6.625	.100

NOTE:
1. Each set must be machined, drilled and etched together.
2. Etch to finish dimensions - minimum of .002 inches per surface
3. All dimensions in inches.

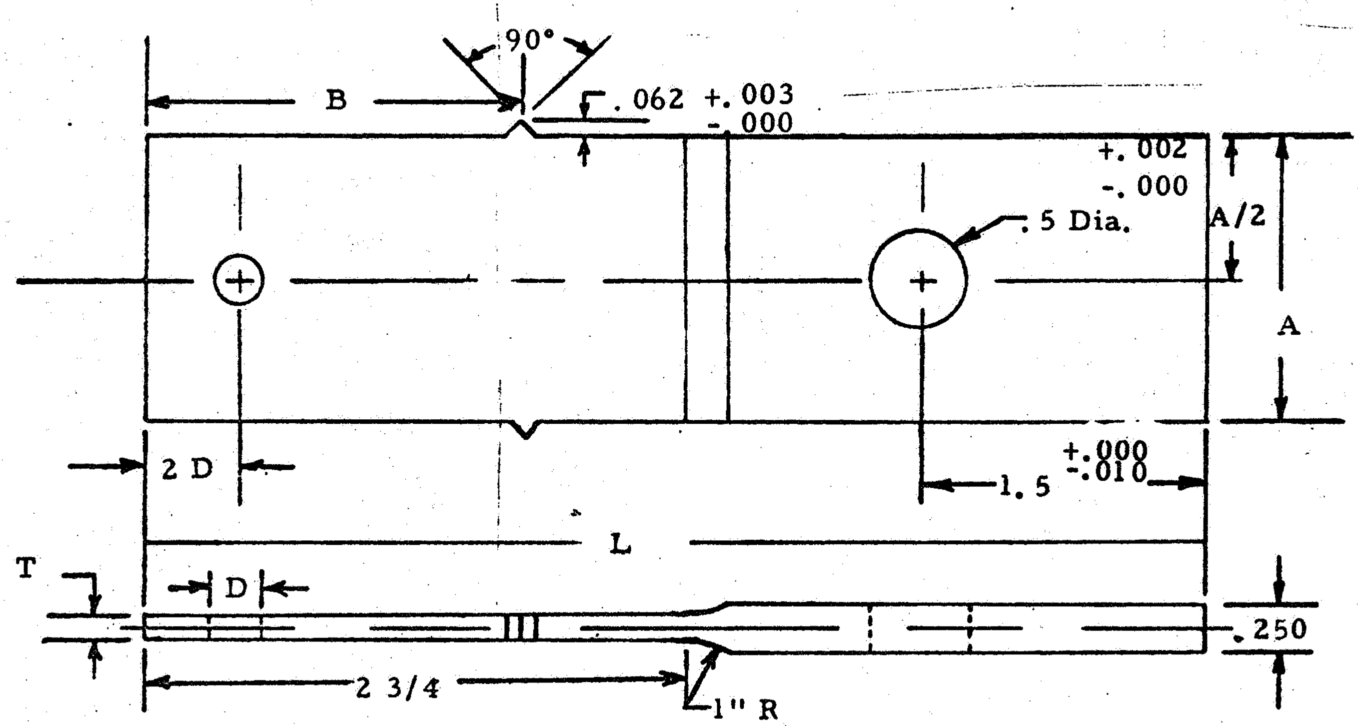
Figure 57 Beryllium Lap Joint Specimen for 100° Flush Head Bolts



ITEM NO.	A $^{+}_{-}$.010	B $^{+}_{-}$.002	D $^{+.002}_{-.000}$	L $^{+}_{-}$.010	T $^{+}_{-}$.001
1	1.500	.950	.190	5.575	.100
2	1.500	1.950	.250	5.575	.100

NOTE:
1. Each set must be machined, drilled and etched together.
2. Etch to finish dimensions - minimum of .002 inches per surface.
3. All dimensions in inches.

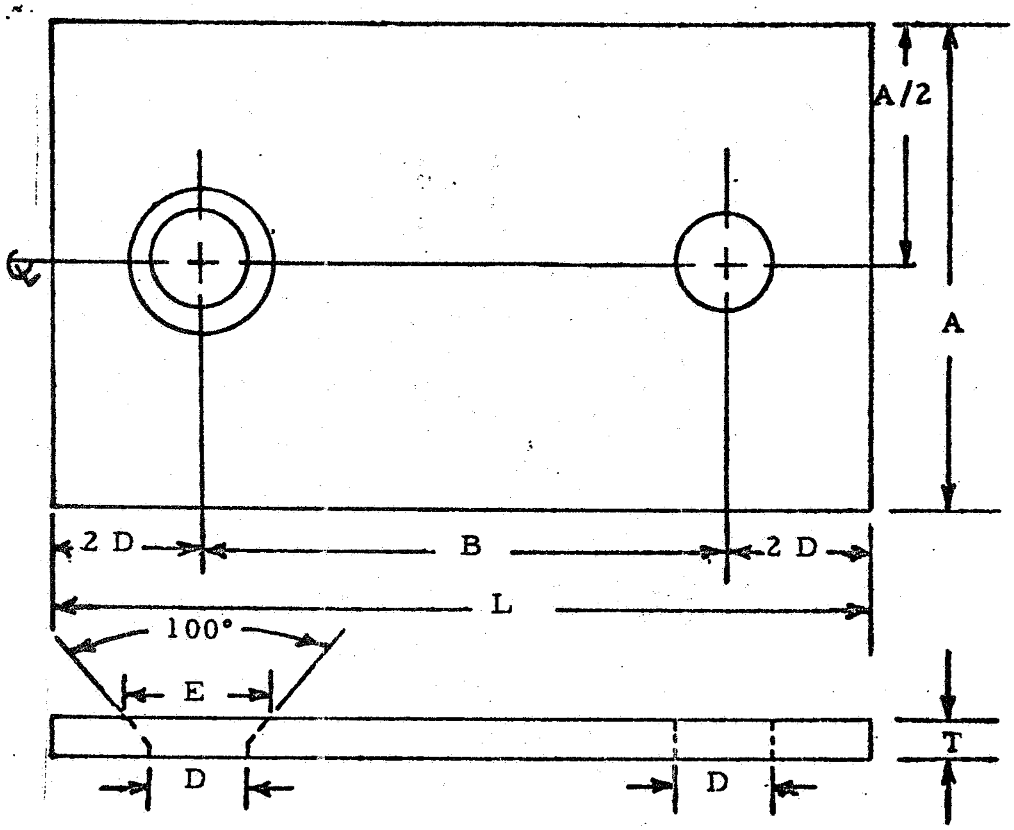
Figure 58 Beryllium Center Section for Butt Joint



ITEM NO.	A $^{+}_{-}.010$	B $^{+}_{-}.002$	D $^{+.002}_{-.000}$	L $^{+}_{-}.010$	T $^{+}_{-}.001$
1	1.500	.950	.190	5.575	.200
2	1.500	1.950	.250	5.575	.200
3	1.875	1.950	.3125	5.575	.200

All dimensions in inches.

Figure 59 Aluminum Center Section for Butt Joint

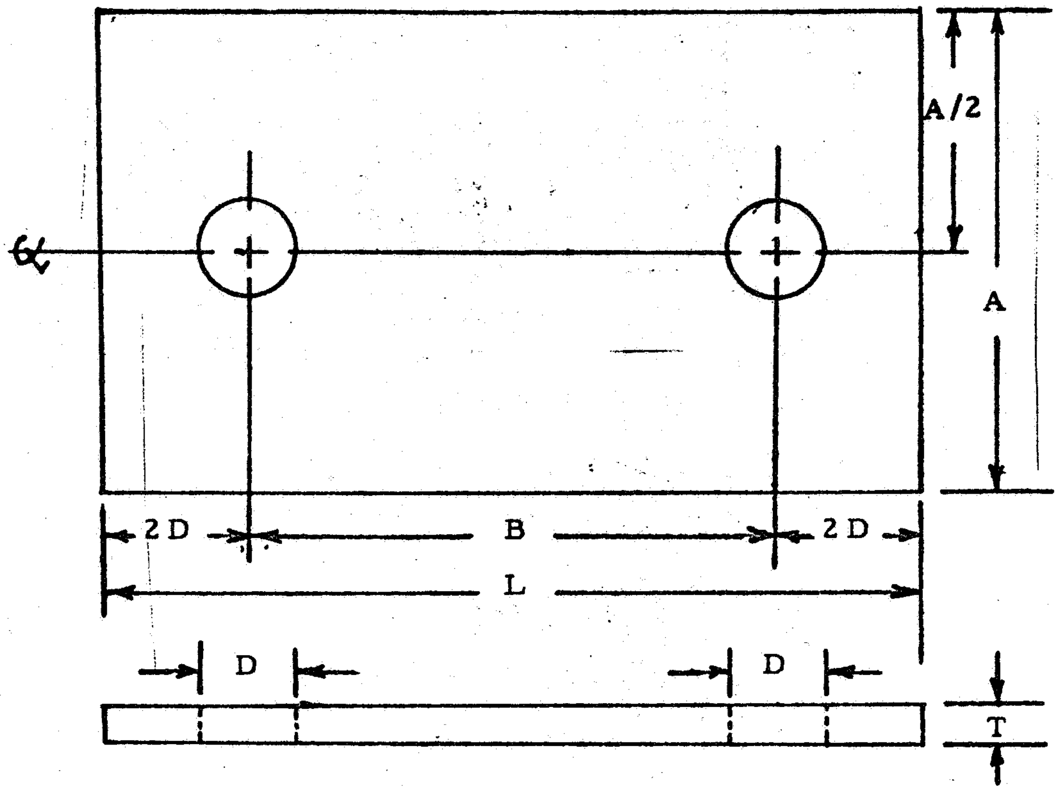


ITEM NO.	±.010 A	Ref. B	±.002 D	±.005 F	+.010 -.001 L	±.001 T
1	1.140	.860	.190	.280	1.62	.100
2	1.500	1.100	.250	.372	2.10	.100
3	1.872	1.348	.3125	.451	2.60	.100

NOTE:

1. Each set must be machined, drilled and etched together (2/set)
2. Etch to finish dimensions minimum of .002 inches per surface
   All dimensions in inches

Figure 60 Engineering Drawing for Beryllium Butt Joint Strap for 100° Flush Head Bolts - Contract NAS8-20158



ITEM No.	±.010 A	Ref. B	±.002 D	±.010 L	±.001 T
1	1.140	.860	.190	1.62	.050
2	1.500	1.100	.250	2.10	.050
3	1.872	1.348	.3125	2.60	.100

NOTE:

1. Each set must be machined, drilled and etched together (2 per set)
2. Etch to finish dimensions - minimum of .002 inches per surface
   All dimensions in inches.

Figure 61. Engineering Drawing for Beryllium Butt Joint Straps for Protruding Head Bolts - Contract NAS8-20158

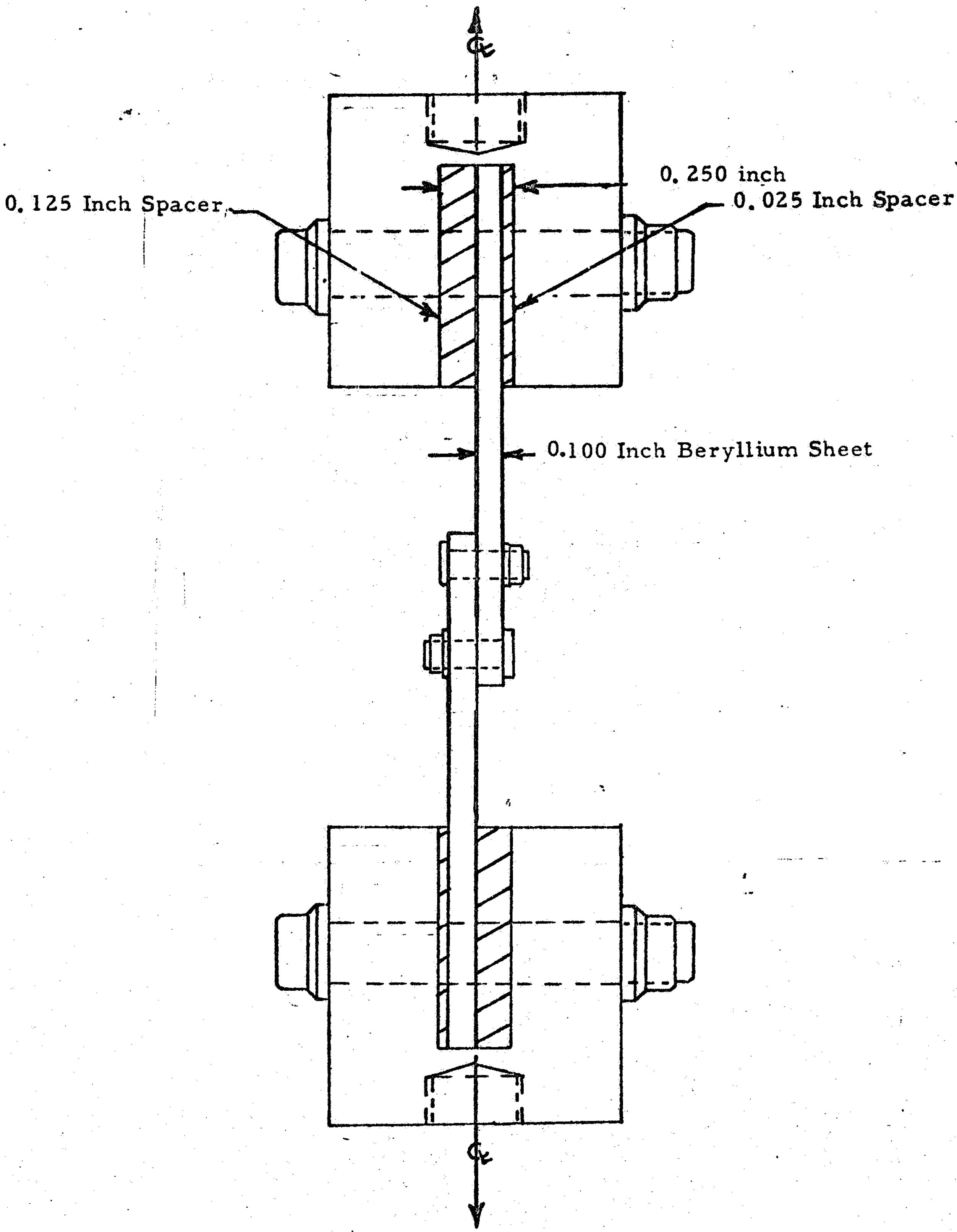


Figure 62. Test Set-up For Beryllium Lap Joint Shear Test

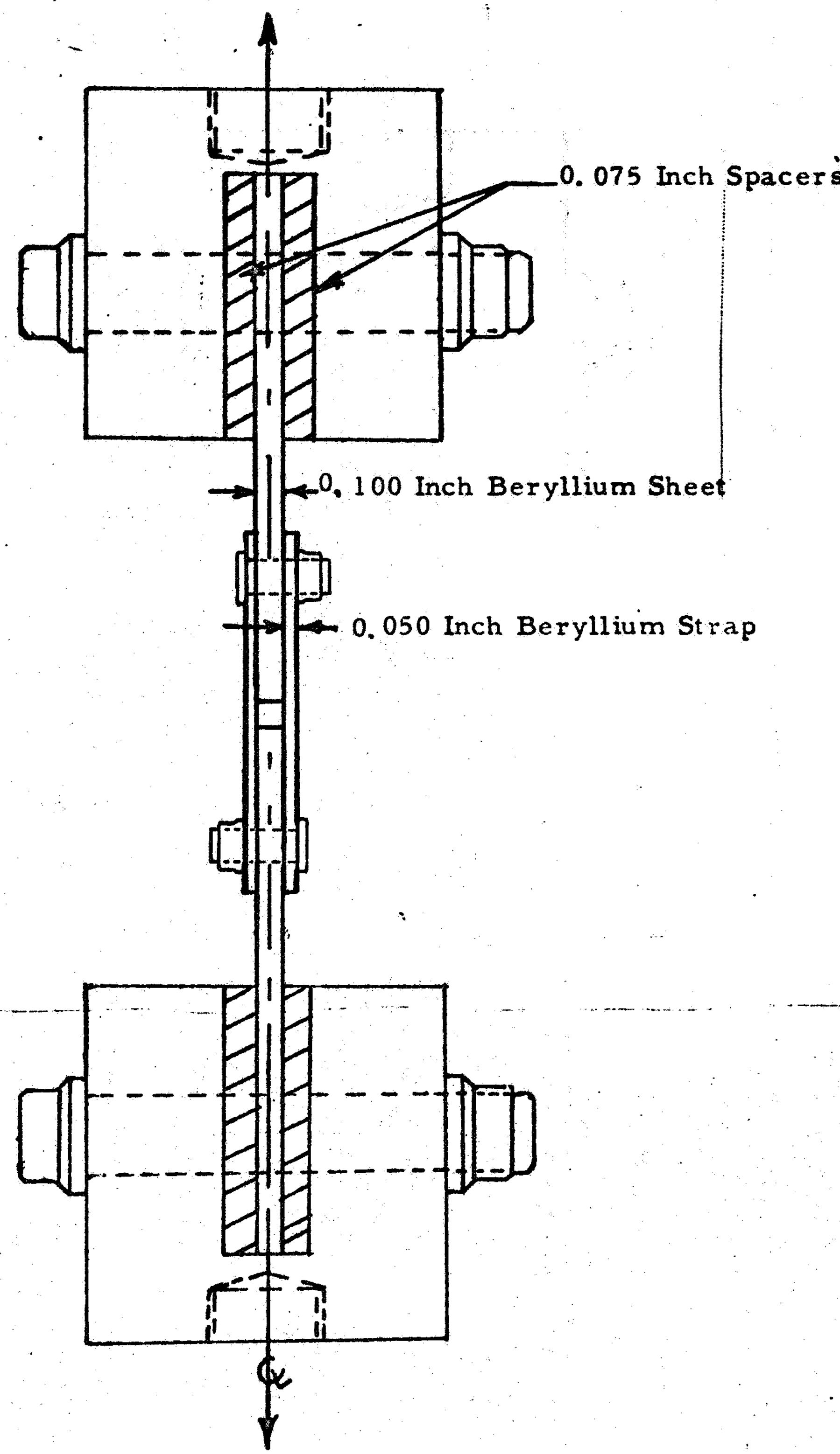


Figure 63. Test Set-up For Beryllium Butt Joint Shear Test

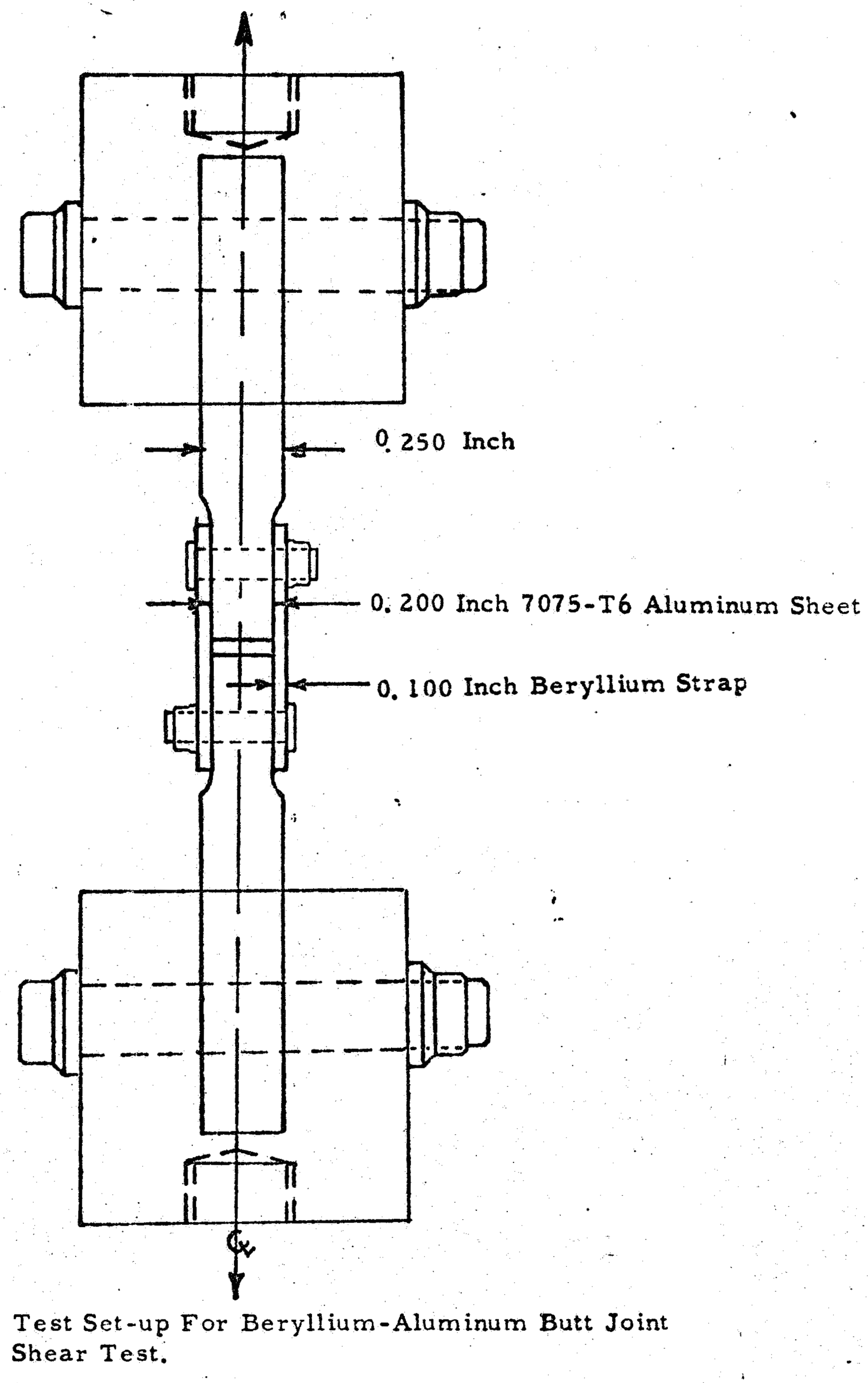


Figure 64. Test Set-up For Beryllium-Aluminum Butt Joint Shear Test.

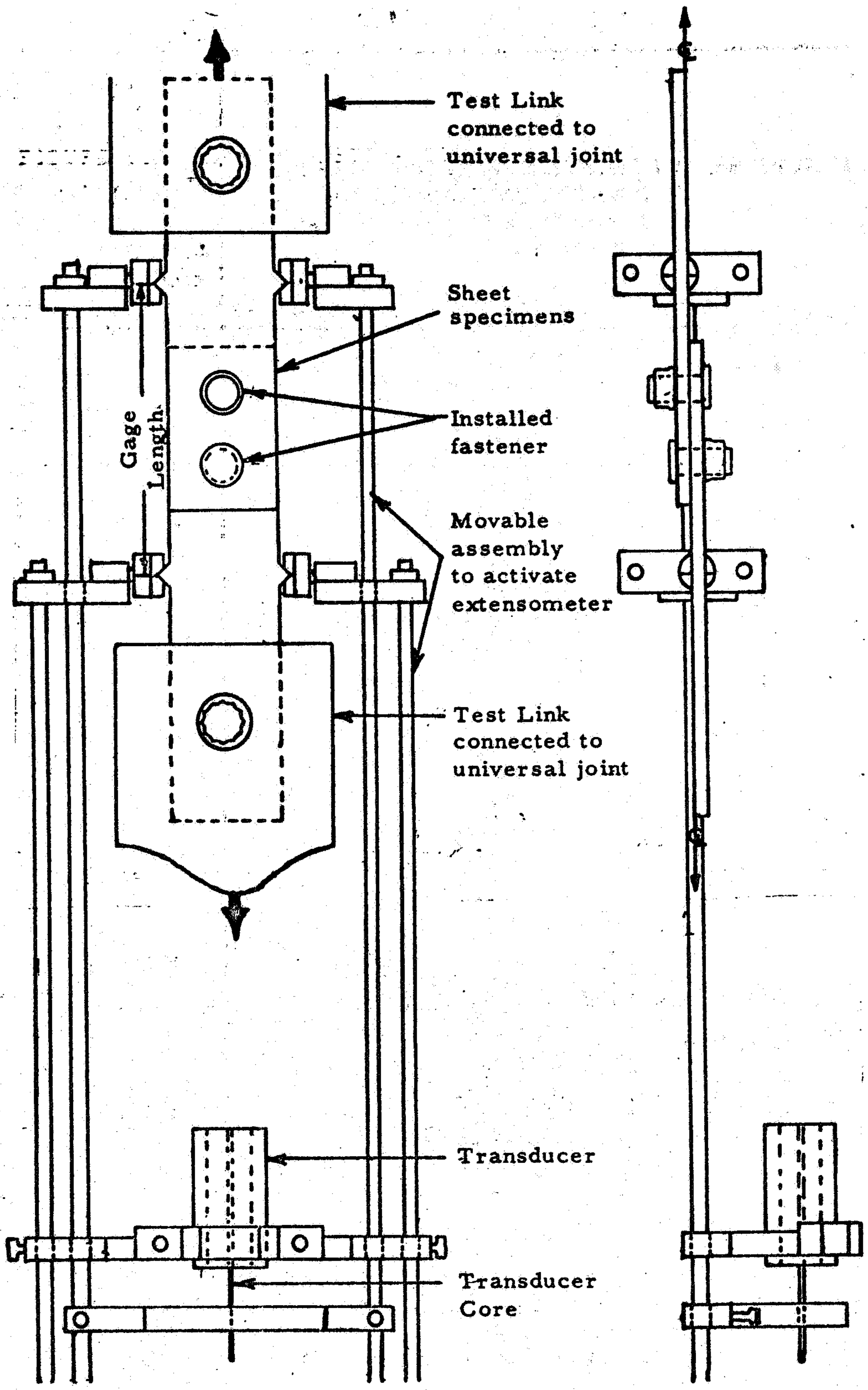


Figure 65. Load Extensometer for Lap and Butt Joint Shear Tests

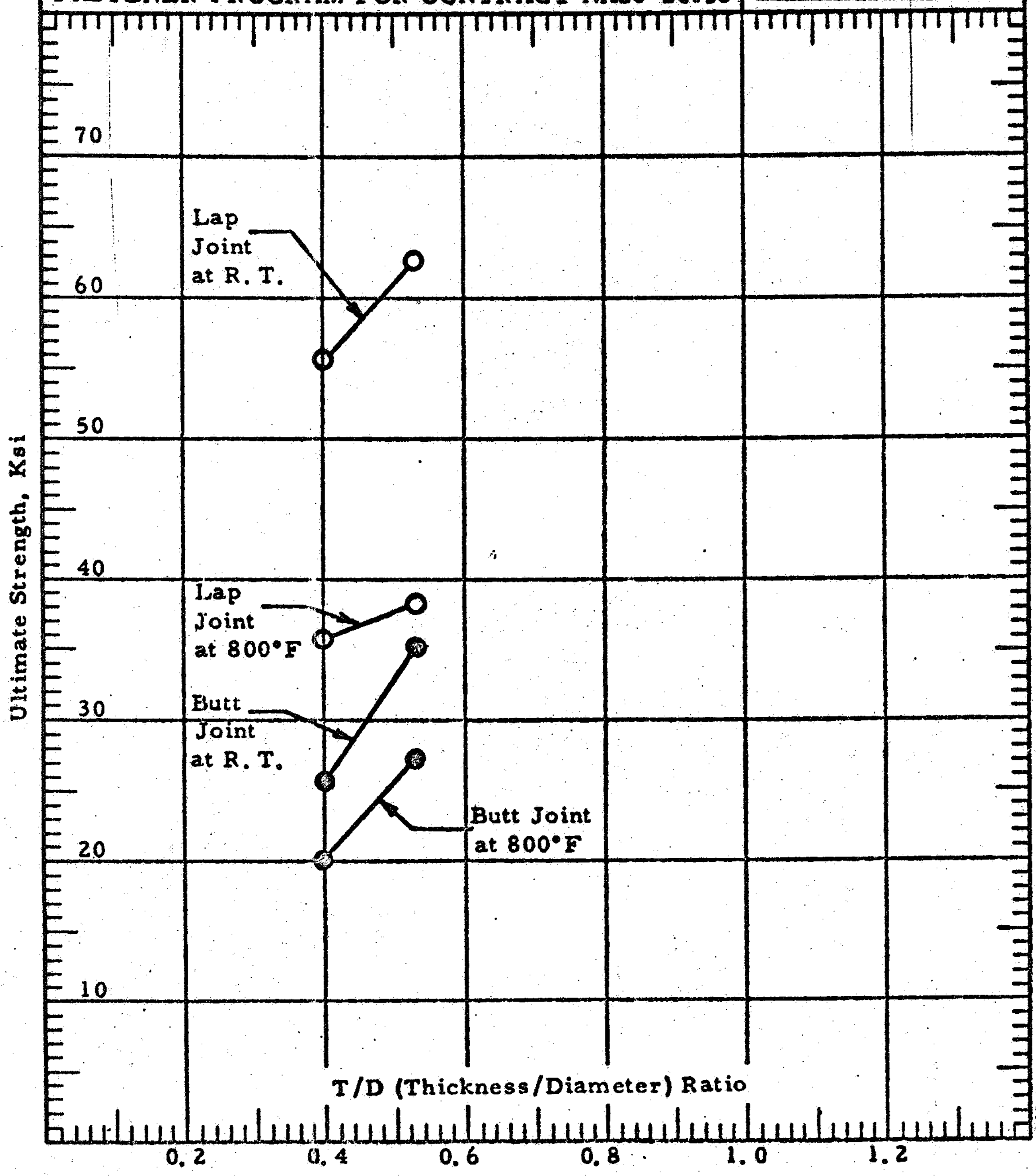
FIGURE 66. ULTIMATE STRENGTH VERSUS T/D RATIO FOR BERYLLIUM LAP JOINTS AND BERYLLIUM BUTT JOINTS

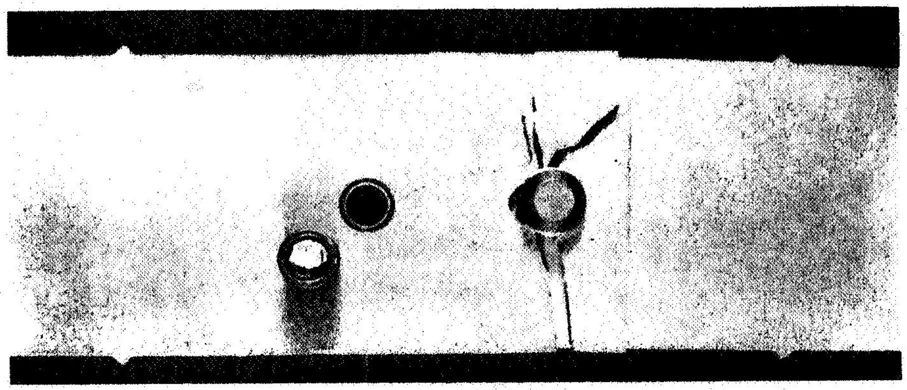
SPS LABORATORIES

Chart No.:

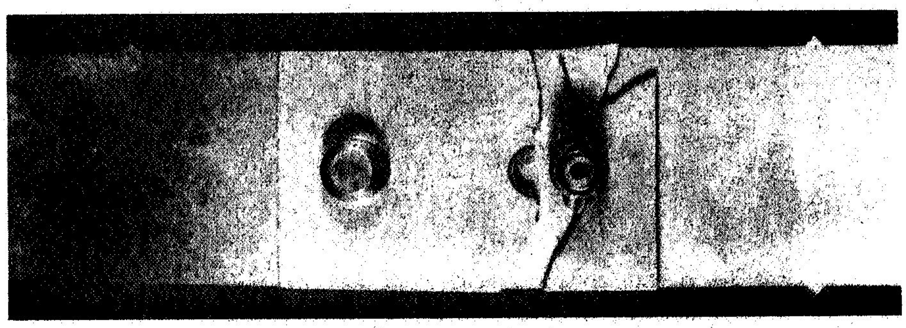
Date:

FASTENER PROGRAM FOR CONTRACT NAS8-20158

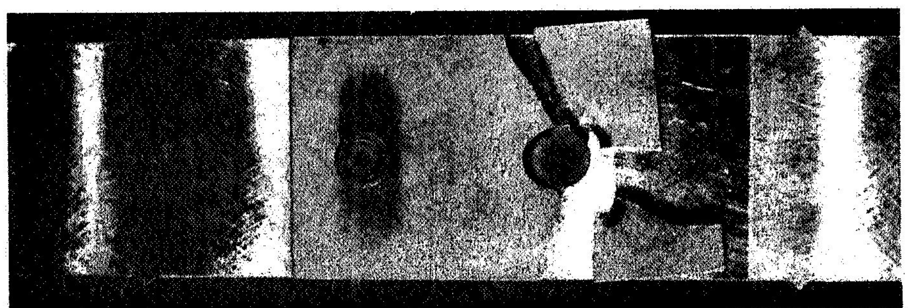




A. Beryllium Lap Joint



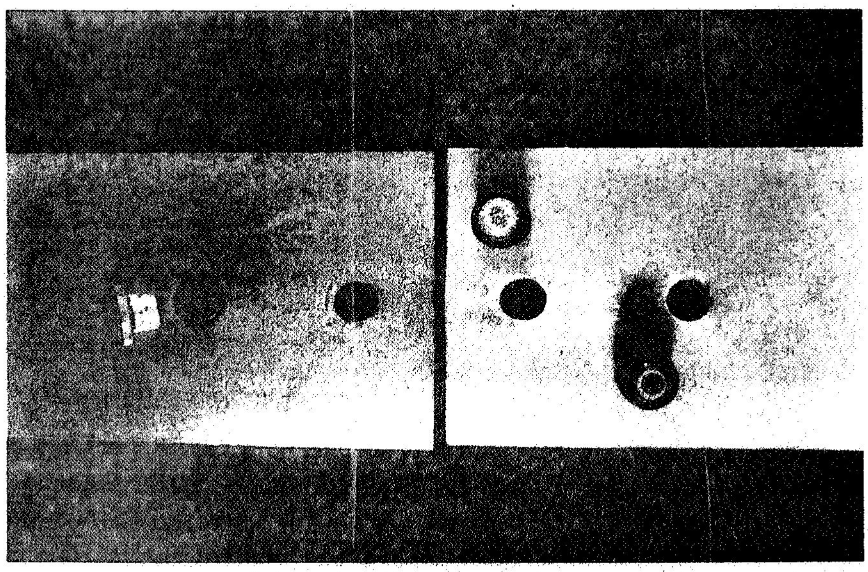
B. Beryllium Butt Joint



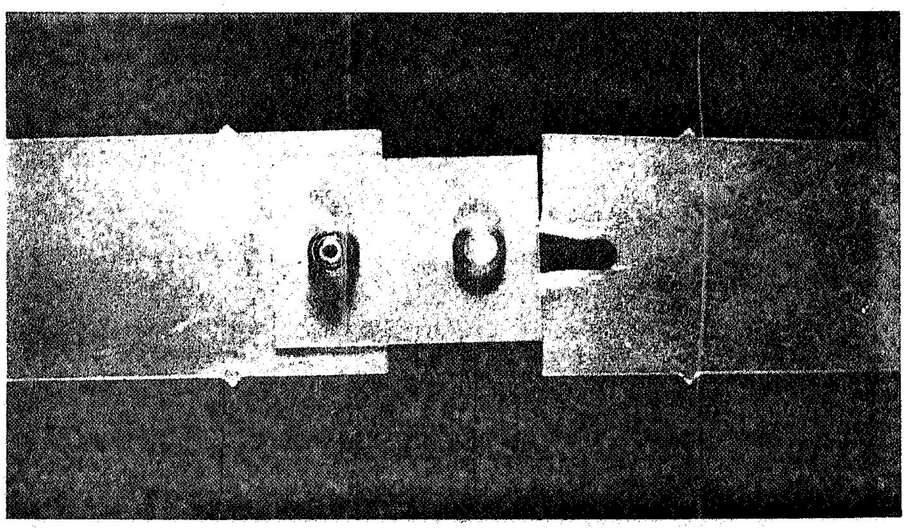
C. Beryllium-Aluminum Butt Joint

Figure 67. Photograph of Lap and Butt Joints Tested at Room Temperature

Note the brittle fractures which were considered tension failures.

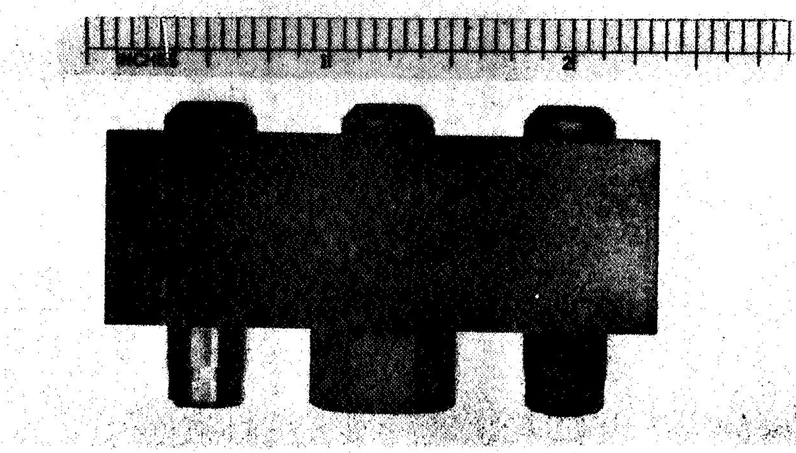


A. Beryllium Lap Joint

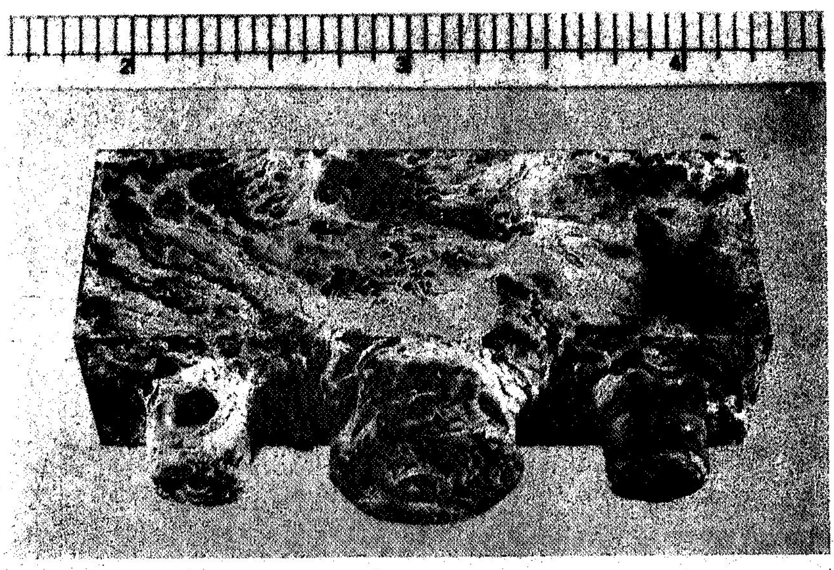


B. Beryllium Butt Joint

Figure 68. Photograph of Lap and Butt Joints Tested at 800°F



Before



After

Figure 69. Photographs of Corrosion Specimen Before and After Accelerated Salt Spray Test. Parts were Tested for 72 hours in a 5% Na Cl Atmosphere.

TABLE XIX

MECHANICAL PROPERTIES

Bolt Part No.: PDP 16-6-18; Material: Forward Extruded Berylco XT-20
Configuration: Protruding Head Point Drive
Nut Part No.: 68277-6; Material: Annealed 347 Stainless Steel
Configuration: Twist-off Nut
Diameter : #10-32; Grip 0.562 Inches

1. Tensile

A. Fastener Properties

Test No.	Test Temperature, °F	Twist-off Torque, in-lbs.	Preload, lbs.	Preload Stress, psi (1)	Ultimate Load, lbs.	Ultimate Stress, psi (1)
1	Room	25	850	42,500	1750 (T)	87,500
2	Room	28	1500	75,000	1950 (S)	97,500
3	Room	20	1100	55,000	1770 (T)	88,500
4	Room	25	950	47,500	1780 (S)	89,000
5	Room	20	1000	50,000	1640 (T)	82,000
6	800	NA	NA	NA	1100 (H)	55,000
7	800	NA	NA	NA	1130 (H)	56,300
8	800	NA	NA	NA	1100 (H)	55,000
9	800	NA	NA	NA	1240 (H)	62,000
10	800	NA	NA	NA	1130 (H)	56,300

(1) Stress Calculated at Tensile Stress Area of 0.01999 Square Inches
(T) Bolt Thread Failure
(S) Bolt Shank Failure
(H) Head Failure
NA- Not Applicable

TABLE XIX (continued)

Bolt Part No. : PDP 16-6-18
Nut Part No. : 68277-6
Diameter : #10-32

2. Shear

A. Double Shear

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)
1	Room	3740	66,000
2	Room	3980	70,200
3	Room	5000	88,200
4	Room	3900	68,800
5	Room	4080	72,000
6	800	1800	31,700
7	800	2000	35,300
8	800	1900	33,600
9	800	2010	35,500
10	800	1875	33,100

(2) Stress Calculated at Twice Nominal Diameter Area, 0.0567 Square Inches

TABLE XIX (continued)

Bolt Part No. : PDP 16-6-18
Nut Part No. : 68277-6
Diameter : #10-32 Grip .200 Inches

2. Shear (continued)

B. Lap Joint Shear

Sheet Material - 1800 BL00001 Beryllium
Sheet Thickness - 0.100 Inches
t/d Ratio - 0.526

	Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, KSI (1)	.004 Inches lbs.	.004 Inches KSI	.006 Inches lbs.	.006 Inches KSI	.008 Inches lbs.	.008 Inches KSI	.010 Inches lbs.	.010 Inches KSI	.012 Inches lbs.	.012 Inches KSI	Type of Failure
					Permanent Set Offset Yield Strength										
	1	Room	3400	60.0	3175	56.0	Joint failed before .006" permanent set was attained								B.T.
Item 4	2	Room	3425	60.4	2950	52.0	3175	57.0	3300	58.2	Joint failed before .010" perm. set				T.S.
	3	Room	3600	63.5	2900	51.1	3150	55.6	3275	57.8	3425	60.4	3550	62.6	T.S.
	4	Room	3775	66.6	3325	58.6	3500	61.6	3625	64.0	3750	66.0			T.S.
	5	Room	3575	63.0	3275	57.5	3425	60.4	3525	62.2	Joint failed before .010" perm. set				T.S.
	6	800	2150	37.9	1775	31.3	1825	32.2	1850	32.6	1900	33.4	1950	34.2	S.B.
	7	800	2210	39.0	1725	30.4	1850	32.6	1900	33.4	1950	34.2	2000	35.3	S.B.
Item 5	8	800	2255	39.6	1900	33.4	1950	34.2	2000	35.3	2025	35.6	2075	36.5	S.B.
	9	800	2100	37.0	1650	29.1	1800	31.7	1850	32.6	1875	33.0	1900	33.4	S.B.
	10	800	2050	36.1	1325	23.4	1600	28.2	1750	30.8	1800	31.7	1825	32.2	S.B.

(1) Stress Calculated at Twice Nominal Fastener Diameter Area; 0.0567 Square Inches
B.T. - Bolt Thread Failure
T.S. - Tension Failure of Sheet
S.B. - Shear Failure of Bolt Shank

TABLE XIX (continued)

Bolt Part No.: PDP 16-6-18
Nut Part No. : 68277-6
Diameter : #10-32 Grip .400 Inches

2. Shear (continued)

C. Butt Joint Shear

Sheet Material - Strap - 1800 - BL 00001 Beryllium
Thickness - 0.050 Inches
Center Sheet - 1800 - BL 00001 Beryllium
Thickness - 0.100 Inches
t/d Ratio - 0.526

	Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, KSI (1)	Permanent Set Offset Yield Strength .004 Inches lbs.	.004 Inches KSI	.006 Inches lbs.	.006 Inches KSI	.008 Inches lbs.	.008 Inches KSI	.010 Inches lbs.	.010 Inches KSI	.012 Inches lbs.	.012 Inches KSI	Type of Failure
	1	Room	1975	34.8	Joint failed before .004" permanent set was attained										S.C.S.
	2	Room	1900	33.4	1475	26.0	1750	30.8	Joint failed before .008" permanent set						S.C.S.
	3	Room	1900	33.4	Joint failed before .004" permanent set was attained										T.S.
Item 6	4	Room	1900	33.4	Joint failed before .004" permanent set was attained										S.C.S.
	5	Room	2250	39.6	1050	18.5	1575	27.8	1875	33.0	2025	35.6	2100	37.0	T.S.
	6	800	1550	27.3	910	16.0	1025	18.1	1085	19.1	1150	20.3	1185	20.9	S.C.S.
	7	800	1460	25.7	925	16.3	1050	18.5	1100	19.4	1135	20.0	1175	20.7	S.C.S.
Item 7	8	800	1575	27.8	1000	17.6	1115	19.6	1175	20.7	1225	21.6	1250	22.0	S.C.S.
	9	800	1525	26.9	935	16.5	1075	19.0	1150	20.3	1200	21.2	1225	21.6	S.C.S.

(1) Stress Calculated at Twice Nominal Fastener Diameter Area; 0.0567 Square Inches
S.C.S. - Shear Failure of Center Sheet
T.S. - Tension Failure of Center Sheet ;

TABLE XIX (continued)

Bolt Part No. : PDP 16-6-18
Nut Part No. : 68277-6
Diameter : #10-32

3. Tension-Tension Fatigue

Maximum Stress - 45,000 psi (3)
Minimum Stress - 4,500 psi
Test Temperature - Room

Test No.	Cycles to Failure	Location of Failure
1	1,100,900	Thread
2	93,500	Thread
3	2,514,000	No Failure
4	1,835,000	No Failure
5	2,500,000	No Failure

(3) Stress Calculated at Basic Minor Diameter Area of 0.01753 Square Inches

TABLE XX

MECHANICAL PROPERTIES

Bolt Part No.: PTF 16-3-9 Material: Forward Extruded Berylco XT-20
Configuration: 100° Flush Head Point Drive
Nut Part No.: 68277-6 Material: Annealed 347 Stainless Steel
Configuration: Twist-off Nut
Diameter: : #10-32 Grip 0.562 Inches

Because of the low yield in the fabrication of these parts, only lap and butt joint shear tests were conducted.

1. Shear

A. Double Shear

Properties at room and 800°F the same as those recorded in Table XIX. Both configurations were fabricated from the same lot of extruded blanks.

B. Lap Joint Shear (Bolt Grip 0.200 Inches)

Sheet Material - 1800 BL00001 Beryllium
Sheet Thickness - 0.100 Inches
t/d Ratio - 0.526

	Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, KSI (1)	Permanent Set Offset Yield Strength: .004 Inches lbs.	.004 Inches KSI	.006 Inches lbs.	.006 Inches KSI	.008 Inches lbs.	.008 Inches KSI	.010 Inches lbs.	.010 Inches KSI	.012 Inches lbs.	.012 Inches KSI	Type of Failure
	1	Room	3975	70.0	3175	57.0	3325	58.6	3450	60.8	3575	63.1	3700	65.3	T.S.
	2	Room	3900	68.7	2875	50.7	3125	55.1	3275	57.8	3400	60.0	3500	61.7	T.S.
Item 1	3	Room	3525	62.2	3200	56.4	3300	58.2	3400	60.0	3500	61.7	-	-	T.S.
	4	Room	3950	69.7	2100	37.0	2625	46.3	2900	51.1	3050	53.8	3200	56.4	T.S.
	5	Room	3600	63.5	2225	39.2	2600	45.9	2850	50.3	3000	52.9	3100	54.7	T.S.
	6	800	2215	39.1	2000	35.3	2050	36.2	2090	36.9	2125	37.5	2150	37.9	S.B.
Item 2	7	800	1980	34.9	1500	26.5	1600	28.2	1675	29.5	1725	30.4	1775	31.3	S.B.
	8	800	1990	35.1	975	17.2	1525	26.9	1625	28.7	1725	30.4	1750	30.9	S.B.
	9	800	2070	36.5	1200	21.2	1475	26.0	1625	28.7	1725	30.4	1775	31.3	S.B.

(1) Stress Calculated at Twice Nominal Fastener Diameter Area; 0.0567 Square Inches
T.S. - Tension Failure of Sheet
S.B. - Shear Failure of Bolt Shank

TABLE XX (continued)

Bolt Part No.: PTF 16-3
Nut Part No. : 68277-6
Diameter : #10-32

1. Shear (continued)

C. Butt Joint Shear (Bolt Grip .400 Inches)

Sheet Material - Strap - 1800 BL00001 Beryllium
Thickness - 0.100 Inches
Center Sheet - 7075-T6 Aluminum
Thickness - 0.200 Inches
t/d Ratio - 1.05

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, KSI (1)	Permanent Set Offset Yield Strength .004 Inches lbs.	.004 Inches KSI	.006 Inches lbs.	.006 Inches KSI	.008 Inches lbs.	.008 Inches KSI	.010 Inches lbs.	.010 Inches KSI	.012 Inches lbs.	.012 Inches KSI	Type of Failure
1	Room	3525	62.2	2300	40.6	2625	46.3	2700	47.6	2950	52.0	3050	53.8	T.S.
2	Room	3450	60.8	2600	45.9	2800	49.4	3025	53.4	3150	55.6	3275	57.8	T.S.
Item 3 3	Room	3475	61.3	2200	38.8	2525	44.5	2750	48.5	2925	51.6	3025	53.4	T.S.
4	Room	3125	55.1	2175	38.4	2550	45.0	2750	48.5	2850	50.3	2950	52.0	T.S.
5	Room	2950	52.0	2475	43.7	2550	45.0	2750	48.5	2850	50.3	-	-	T.S.
6	800													
7	800													
8	800			TESTS WERE NOT CONDUCTED AT 800°F										
9	800													
10	800													

(1) Stress Calculated at Twice Nominal Fastener Diameter, 0.0567 Square Inches
T.S. - Tension Failure of Straps

TABLE XXI

MECHANICAL PROPERTIES

Bolt Part No. : PDP 16-8-24; Material : Forward Extruded Beryclo XT-20
Configuration : Protruding Head Point Drive
Nut Part No. : 68277-8; Material: Annealed 347 Stainless Steel
Configuration : Twist-Off Nut
Diameter : 1/4-28 Grip - 0.750 Inches

1. Tensile

A. Material Properties - 0.113 inch specimen

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation Gage 0.5 in., %	Reduction of Area, %
1	Room	101,200	79,500	(a)	
2	Room	Specimen failed in the thread area			
3	Room	103,100	90,600	4.0	2.0
4	Room	104,100	85,900	(a)	
5	Room	105,600	89,500	(a)	

(a) Ductility could not be determined, specimen fractured into several pieces.

TABLE XXI (continued)

Bolt Part No. : PDP 16-8-24
Nut Part No. : 68277-8
Diameter : 1/4-28

1. Tensile (continued)

B. Fastener Properties

Test No.	Test Temperature, °F	Twist-Off Torque, in-lbs.	Preload lbs.	Preload Stress, psi (1)	Ultimate Load, lbs.	Ultimate Stress, psi
1	Room	50	2000	55,000	3200 (T)	88,000
2	Room	30	1150	31,600	1950 (T)	53,600
3	Room	Bolt threads failed during installation at 40 in-lbs.				
4	Room	40	1975	54,400	2560 (T)	70,400
5	Room	40	1950	53,600	3380 (T)	92,900
1	800	NA	NA	NA	1700 (H)	52,200
2	800	NA	NA	NA	1740 (H)	47,800
3	800	NA	NA	NA	1625 (TS)	44,700
4	800	NA	NA	NA	2080 (TS)	57,200
5	800	NA	NA	NA	1635 (H)	45,000

(1) Stress Calculated at Tensile Stress Area of 0.03637 Square Inches
(T) Thread Failure
(H) Head Failure
(TS) Threads Stripped

TABLE XXI (continued)

Bolt Part No. : PDP 16-8-24
Nut Part No. : 68277-8
Diameter : 1/4-28

2. Shear (continued)

A. Double Shear

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)
1	Room	9170	93,700
2	Room	9180	93,500
3	Room	9430	96,000
4	Room	8600	87,600
5	Room	8940	91,100
6	800	3575	36,400
7	800	3400	34,600
8	800	3740	38,100
9	800	3850	39,200
10	800	3130	31,900

(2) Stress Calculated at Twice Nominal Diameter Area, 0.09817 Square Inches

TABLE XXI (continued)

Bolt Part No.: PDP 16-8
Nut Part No. : 68277-8
Diameter = 1/4-28

2. Shear (continued)

B. Lap Joint Shear (Bolt Grip .200 Inches)

Sheet Material - 1800 - BL00001 Beryllium
Sheet Thickness - 0.100 Inches
t/d Ratio - 0.400

	Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, KSI (1)	Permanent Set Offset Yield Strength .004 Inches lbs.	.004 Inches KSI	.006 Inches lbs.	.006 Inches KSI	.008 Inches lbs.	.008 Inches KSI	.010 Inches lbs.	.010 Inches KSI	.012 Inches lbs.	.012 Inches KSI	Type of Failure
	1	Room	6000	61.1	4750	48.4	4950	50.4	5100	52.0	5225	53.2	5325	54.2	T.S.
	2	Room	4950	50.4	4750	48.4	Joint failed before .006" permanent set was attained								T.S.
Item 8	3	Room	4800	48.9	4450	45.3	4775	48.6	Joint failed before .008" permanent set						T.S.
	4	Room	5950	60.6	4050	41.3	4475	45.6	4700	47.9	4900	49.9	5025	51.2	T.S.
	5	Room	5600	57.0	3450	35.1	4150	42.3	4475	45.6	4700	47.9	4850	49.4	T.S.
	6	800	3500	35.7	2650	27.0	2860	29.1	2925	29.8	2950	30.0	2975	30.3	S.B.
Item 9	7	800	3575	36.4	2900	29.5	3025	30.8	3075	31.3	3100	31.6	3150	32.1	S.B.
	8	800	3550	36.2	2650	27.0	2875	29.3	2950	30.3	3000	30.6	3050	31.1	S.B.
	9	800	3300	33.6	2600	26.5	2775	28.3	2825	29.3	2875	29.3	2900	29.5	S.B.
	10	800	3525	35.9	2650	27.0	2875	29.3	2950	30.3	3000	30.6	3050	31.1	S.B.

(1) Stress Calculated at Twice Nominal Fastener Diameter Area, 0.09817 Square Inches
T.S. - Tension Failure of Sheet
S.B. - Shear Failure of Bolt Shank

TABLE XXI (continued)

Bolt Part No.: PDP 16-8
Nut Part No. : 68277-8
Diameter : 1/4-28 Grip .400 Inches

2. Shear (continued)

C. Butt Joint Shear (Bolt Grip .400 Inches)

Sheet Material - Strap - 1800 - BL00001 Beryllium
Thickness - 0.050 Inches
Center Sheet - 1800 - BL00001 Beryllium
Thickness - 0.100 Inches
t/d Ratio - 0.400

	Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, KSI (1)	Permanent Set Offset Yield Strength .004 Inches lbs.	.004 Inches KSI	.006 Inches lbs.	.006 Inches KSI	.008 Inches lbs.	.008 Inches KSI	.010 Inches lbs.	.010 Inches KSI	.012 Inches lbs.	.012 Inches KSI	Type of Failure
	1	Room	2650	27.0	2375	24.2	2450	25.0	2550	26.0	2600	26.5	-	-	T.S.
	2	Room	2650	27.0	1000	10.2	1350	13.8	1750	17.8	2250	22.9	2400	24.4	T.S.
Item 13	3	Room	2550	26.0	1050	10.7	1475	15.0	1900	19.4	2225	22.7	2425	24.7	T.S.
	4	Room	2225	22.7	725	7.4	1075	11.0	1625	16.6	2025	20.6	-	-	T.S.
	5	Room	2450	25.0	2050	20.9	2300	23.4	2425	24.7	-	-	-	-	T.S.
	6	800	2000	20.4	1025	10.4	1425	14.5	1550	15.8	1625	16.6	1675	17.1	S.C.S.
	7	800	2025	20.6	850	8.7	1250	12.7	1450	14.8	1525	15.5	1575	16.0	S.C.S.
Item 14	8	800	1825	18.6	875	8.9	1200	12.2	1400	14.3	1425	14.5	1450	14.8	S.C.S.
	9	800	1950	19.7	1350	13.8	1435	14.6	1525	15.5	1565	15.9	1610	16.4	S.C.S.
	10	800	2050	20.9	900	9.2	1300	13.2	1435	14.6	1500	15.3	1550	15.8	S.C.S.

(1) Stress Calculated at Twice Nominal Fastener Diameter Area, 0.09817 Square Inches
T.S. - Tension Failure of Straps
S.C.S. - Shear Failure of Center Sheet

TABLE XXI (continued)

Bolt Part No. : PDP 16-8-24
Nut Part No. : 68277-8
Diameter : 1/4-28

3. Tension-Tension-Fatigue

Maximum Stress - 45, 000 psi (3)
Minimum Stress - 4, 500 psi
Test Temperature - Room

Test No.	Cycles to Failure	Location of Failure
1	Hexagon Recess Split During Assembly	
2	Hexagon Recess Split During Assembly	
3	2, 380, 700	No Failure
4	2, 434, 100	No Failure
5	7, 267, 000	No Failure
6	2, 465, 100	No Failure

(3) Stress Calculated at Basic Minor Diameter Area of 0. 03256 Square Inches

TABLE XXI (continued)

Bolt Part No. : PDP 16-8
Nut Part No. : 68277-8
Diameter : 1/4-28

4. Corrosion Resistance - Accelerated Salt Spray (5% NaCl)

Test No.	Bolt Surface Condition	Bolt Surface Condition	Structure Material	Structure Surface Condition	Seating Torque, in-lbs.	Results
1	Etched	As machined	Hot pressed block	Etched	70	Corrosion of bolt point and head and structure material noted within 24 hours.
2	Etched	Coated with K_4 lube	Hot pressed block	Etched	60	Severe corrosion was noted at these areas after 48 hours.
3	Etched	Etched (Be hexagon nut)	Hot pressed block	Etched	60	

TABLE XXII

MECHANICAL PROPERTIES

Bolt Part No. : PTF 16-4-12; Material: Forward Extruded Berylco XT-20
Configuration : 100° Flush Head Point Drive
Nut Part No. : 68277-8; Material: Annealed 347 Stainless Steel
Configuration : Twist-Off Nut
Diameter : 1/4-28 Grip: 0.750 Inches

1. Tensile

A. Fastener Properties

Test No.	Temperature, °F	Twist-Off Torque, in-lbs.	Preload lbs.	Preload Stress, psi (1)	Ultimate Load, lbs.	Ultimate Stress, psi (1)
1	Room	Bolt threads failed during installation at 50 in-lbs.				
2	Room	30	1500	41,200	1700 (T)	46,700
3	Room	50	2100	57,700	2760 (H)	75,900
4	Room	38	1600	44,000	2680 (T)	73,700
5	Room	42	1650	45,400	2350 (H)	64,500
6	800	NA	NA	NA	1240 (H)	34,100
7	800	NA	NA	NA	1550 (H)	42,000
8	800	NA	NA	NA	1500 (H)	41,200
9	800	NA	NA	NA	1525 (H)	41,900
10	800	NA	NA	NA	1535 (H)	42,200

(1) Stress Calculated at Tensile Stress Area of 0.03637 Square Inches
(T) Bolt Thread Failure
(H) Head Failure
NA - Not Applicable

TABLE XXII (continued)

Bolt Part No. : PTF 16-4
Nut Part No. : 68277-8
Diameter : 1/4-28

2. Shear

A. Double Shear

Properties at room and 800°F the same as those recorded in Table XXI. Both configurations were fabricated from the same lot of extruded blanks.

B. Lap Joint Shear (Bolt Grip 0.200 Inches)

Sheet Material - 1800 - BL00001 Beryllium
Sheet Thickness - 0.100 Inches
t/d Ratio - 0.400

	Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, KSI (1)	Permanent Set Offset Yield Strength .004 Inches lbs.	.004 Inches KSI	.006 Inches lbs.	.006 Inches KSI	.008 Inches lbs.	.008 Inches KSI	.010 Inches lbs.	.010 Inches KSI	.012 Inches lbs.	.012 Inches KSI	Type of Failure
	1	Room	4400	44.8	3325	39.9	3750	38.2	4075	41.5	4250	43.3	4375	44.6	T.S.
	2	Room	5550	56.5	3125	31.9	3850	39.2	4225	43.0	4375	44.6	4500	45.8	T.S.
	3	Room	3800	38.7	Joint failed before .004" permanent set										B.T.
Item 11	4	Room	4775	48.6	3425	34.9	3900	39.7	4200	42.8	4400	44.8	4550	46.3	T.S.
	5	Room	4925	50.0	2550	26.0	3350	34.1	3950	40.2	4250	43.3	4425	45.1	T.S.
	6	800	3550	36.2	2075	21.1	2325	23.7	2450	25.0	2600	26.5	2675	27.2	S.B.
	7	800	3550	36.2	2400	24.4	2650	27.0	2775	28.3	2875	29.3	2950	30.0	S.B.
Item 12	8	800	3800	38.7	2850	29.0	2975	30.3	3100	31.6	3150	32.1	3200	32.6	S.B.
	9	800	3450	35.1	2350	23.9	2600	26.5	2700	27.5	2875	29.3	2950	30.0	S.B.
	10	800	Specimen damaged during test set-up												

(1) Stress Calculated at Twice Nominal Fastener Diameter Area, 0.09817 Square Inches
T.S. - Tension Failure of Sheet
B.T. - Bolt Thread Failure
S.B. - Shear Failure of Bolt Shank

TABLE XXII (continued)

Bolt Part No. : PTF 16-4
Nut Part No. : 68277-8
Diameter : 1/4-28

2. Shear (continued)

C. Butt Joint Shear (Bolt Grip .400 Inches)

Sheet Material - Strap - 1800 - BL00001 Beryllium
Thickness - 0.100 Inches
Center Sheet - 7075-T6 Aluminum
Thickness - 0.200 Inches
t/d Ratio - 0.80

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, KSI (1)	Permanent Set Offset Yield Strength .004 Inches lbs.	.004 Inches KSI	.006 Inches lbs.	.006 Inches KSI	.008 Inches lbs.	.008 Inches KSI	.010 Inches lbs.	.010 Inches KSI	.012 Inches lbs.	.012 Inches KSI	Type of Failure
1	Room	4800	48.9	3250	33.1	4000	40.7	4350	44.3	4500	45.8	4725	48.1	T.S.
2	Room	5400	55.0	3450	35.1	3900	39.7	4225	43.0	4400	44.8	4550	46.3	T.S.
3	Room	5000	50.9	3150	32.1	3900	39.7	4300	43.8	4500	45.8	4650	47.4	T.S.
4	Room	5800	59.1	2900	29.5	3700	37.7	4200	42.8	5000	50.9	5100	52.0	T.S.
5	Room	4600	46.9	3050	31.1	4000	40.7	4350	44.3	4575	46.6	-	-	T.S.
6	800													
7	800													
8	800													
9	800													
10	800													

Tests were not conducted at 800°F

Item 10

(1) Stress Calculated at Twice Nominal Fastener Diatemeter Area, 0.09817 Square Inches
T.S. - Tension Failure of Straps

TABLE XXII (continued)

Bolt Part No.: PTF 16-4-12
Nut Part No.: 68277-8
Diameter : 1/4-28

3. Tension-Tension-Fatigue

Maximum Stress - 45,000 psi (3)
Minimum Stress - 4,500 psi
Test Temperature - Room

Test No.	Cycles to Failure	Location of Failure
1	498,100	Head
2	1,773,000	No Failure
3	1,031,000	No Failure
4	1,272,300	No Failure
5	Hexagon Recess Split During Assembly	
6	246,300	Head

(3) Stress Calculated at Basic Minor Diameter Area of 0.03256 Square Inches

TABLE XXIII

MECHANICAL PROPERTIES

Bolt Part No. : PDP 16-10-30; Material: Forward Extruded Berylco XT-20
Configuration : Protruding Head Point Drive
Nut Part No. : 68277-10; Material: Annealed 347 Stainless Steel
Configuration : Twist-Off Nut
Diameter : 5/16-24 Grip: 0.937 Inches

1. Tensile

A. Material Properties - 0.113 Inch Specimen

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation (Gage, 0.5 in. %	Reduction of Area, %
1	Room	105,000	91,000	4.0	1.6
2	Room	97,000	87,200	(a)	
3	Room	97,200	79,400	(a)	
4	Room	112,000	72,000	8.0	8.5
5	Room	108,000	86,000	2.0	2.1
6	800	54,000	53,000	10.0	22.8
7	800	50,000	49,000	16.0	29.5
8	800	52,600	52,500	12.0	30.8
9	800	60,700	59,800	10.0	16.6
10	800	59,100	58,600	8.0	22.4

(a) Ductility Could Not Be Determined, Specimen Fractured Into Several Pieces

TABLE XXIII (continued)

Bolt Part No. : PDP 16-10-30
Nut Part No. : 68277-10
Diameter : 5/16-24

1. Tensile (continued)

B. Fastener Properties

Test No.	Test Temperature, °F	Twist-Off Torque, in-lbs.	Preload, lbs.	Preload Stress, psi (1)	Ultimate Load, lbs.	Ultimate Stress, psi (1)
1	Room	60	2900	50,000	4460 (T)	76,800
2	Room	50	2140	36,900	4460 (H)	76,800
3	Room	90	3800	65,500	4400 (H)	75,800
4	Room	65	2875	49,500	4620 (T)	79,600
5	Room	70	2675	46,000	5500 (T)	94,700
6	800	NA	NA	NA	3100 (H)	53,400
7	800	NA	NA	NA	2885 (H)	49,700
8	800	NA	NA	NA	2800 (H)	48,200
9	800	NA	NA	NA	3160 (H)	54,400
10	800	NA	NA	NA	3440 (H)	59,300

(1) Stress Calculated at Tensile Stress Area of 0.05805 Square Inches
(T) Bolt Thread Failure
(H) Head Failure
NA - Not Applicable

TABLE XXIII (continued)

Bolt Part No. : PDP 16-10
Nut Part No. : 68277-10
Diameter : 5/16-24

2. Shear (continued)

B. Butt Joint Shear (Bolt Grip .400 Inches)

Sheet Material - Strap - 1800 BL00001 Beryllium
Thickness - 0.100 Inches
Center Sheet - 7075-T6 Aluminum
Thickness - 0.200 Inches
t/d Ratio - 0.642

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, KSI (1)	Permanent Set Offset Yield Strength .004 Inches lbs.	.004 Inches KSI	.006 Inches lbs.	.006 Inches KSI	.008 Inches lbs.	.008 Inches KSI	.010 Inches lbs.	.010 Inches KSI	.012 Inches lbs.	.012 Inches KSI	Type of Failure
1	Room	6500	42.5	6060	39.6	6140	40.1	6250	40.8	Failed before .010" perm. set				T.S.
2	Room	6250	40.8	3500	22.9	4500	29.4	5000	32.7	5395	35.3	5625	36.8	T.S.
3	Room	6700	43.8	3250	21.2	4625	30.2	5310	34.7	5625	36.8	5810	38.0	T.S.
4	Room	6250	40.8	3500	22.9	4575	29.9	5300	34.6	5550	36.3	6000	39.2	T.S.
5	Room	6250	40.8	5750	37.6	6000	39.2	6125	40.0	Failed before .010" perm. set				T.S.
6	800			Tests were not conducted at 800°F										
7	800													
8	800													
9	800													
10	800													

(1) Stress Calculated at Twice Nominal Fastener Diameter Area, 0.1530 Square Inches
T.S. - Tension Failure of Straps

Item 16

TABLE XXIII (continued)

Bolt Part No. : PDP 16-10-30
Nut Part No. : 68277-10
Diameter : 5/16-24

2. Shear

A. Double Shear

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)
1	Room	12,200	79,700
2	Room	12,200	79,700
3	Room	11,900	77,800
4	Room	12,050	78,800
5	Room	11,900	77,800
6	800	5,750	37,600
7	800	5,580	36,500
8	800	5,450	35,600
9	800	5,960	39,000
10	800	5,400	35,300

(2) Stress Calculated at Twice Nominal Diameter Area, 0.1530 Square Inches

TABLE XXIII (continued)

Bolt Part No.: PDP 16-10-30
Nut Part No. : 68277-10
Diameter : 5/16-24

3. Tension-Tension-Fatigue

Maximum Stress - 45,000 psi (3)
Minimum Stress - 4,500 psi
Test Temperature - Room

Test No.	Cycles to Failure	Location of Failure
1	1,392,000	No Failure
2	51,400	Thread
3	769,000	Thread
4	16,300	Thread
5	Failed Loading	

(3) Stress Calculated at Basic Minor Diameter Area of 0.05242 Square Inches

TABLE XXIV

MECHANICAL PROPERTIES

Bolt Part No. : PTF 16-5-15; Material: Forward Extruded Berylco XT-20
Configuration : 100° Flush Head Point Drive
Nut Part No. : 68277-10; Material: Annealed 347 Stainless Steel
Configuration : Twist-Off Nut
Diameter : 5/16-24 Grip: 0.937 Inches

1. Tensile

A. Fastener Properties

Test No.	Test Temperature, °F	Twist-Off Torque in-lbs.	Preload, lbs.	Preload Stress, psi (1)	Ultimate Load, lbs.	Ultimate Stress, psi (1)
1	Room	58	1650	28,400	3,120 (H)	53,700
2	Room	50	1800	31,000	2,620 (H)	45,100
3	Room	70	Bolt threads failed prior to installation of assembly in tensile machine fixtures			
4	Room	Bolt threads failed during installation at 80-in-lbs.				
5	Room	Bolt threads failed during installation				
6	Room					
7	800	NA	NA	NA	2300 (H)	39,600
8	800	NA	NA	NA	2270 (H)	39,100
9	800	NA	NA	NA	2375 (H)	40,900
10	800	NA	NA	NA	2175 (H)	37,500
11	800	NA	NA	NA	2100 (H)	36,000

(1) Stress Calculated At The Tensile Stress Area of 0.05805 Square Inches
(H) Head Failure

TABLE XXIV (continued)

Bolt Part No.: PTF 16-5-15
Nut Part No. : 68277-10
Diameter : 5/16-24

2. Shear

A. Double Shear

Properties at room and 800°F the same as those recorded in Table XXIII. Both configurations were fabricated from the same lot of extruded blanks.

B. Butt Joint Shear (Bolt Grip 0.400 Inches)

Sheet Material - Strap - 1800 BL00001 Beryllium
Thickness - 0.100 Inches
Center Sheet - 7075-T6 Aluminum
Thickness - 0.200 Inches
t/d Ratio - 0.642

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, KSI (1)	.004 Inches lbs.	.004 Inches KSI	.006 Inches lbs.	.006 Inches KSI	.008 Inches lbs.	.008 Inches KSI	.010 Inches lbs.	.010 Inches KSI	.012 Inches lbs.	.012 Inches KSI	Type of Failure
1	Room	5825	38.1	3000	19.6	3750	24.5	4250	27.8	4750	31.0	5075	33.2	T.S.
2	Room	5850	38.2	2400	15.7	3500	22.9	4250	27.8	4850	31.7	5150	33.7	T.S.
3	Room	4800	31.4	Failed before .004" permanent set was attained										
4	Room	5700	37.3	2150	14.1	3100	20.3	3800	24.8	4325	28.3	4775	31.2	T.S.
5	Room	6100	40.0	1750	11.4	2250	14.7	2950	19.3	3700	24.2	4400	28.8	T.S.
6	800			Tests were not conducted at 800°F										
7	800													
8	800													
9	800													
10	800													

(1) Stress Calculated at Twice Nominal Fastener Diameter Area, 0.1530 Square Inches
T.S. - Tension Failure of Straps

Item 15

TABLE XXIV (continued)

Bolt Part No. : PTF 16-5-15
Nut Part No. : 68277-10
Diameter : 5/16-24

3. Tension-Tension Fatigue

Test No.	Minimum Stress, psi (3)	Maximum Stress, psi	Cycles to Failure	Location of Failure
1	4, 500	45, 000	226, 600	Head
2	4, 500	45, 000	Failed loading	
3	4, 000	40, 000	37, 100	Head
4	3, 500	35, 000	120, 500	Head
5	3, 500	35, 000	25, 300	Head

(3) Stress Calculated at Basic Minor Diameter Area of 0. 05242 Square Inches

TABLE XXV

DISTRIBUTION OF JOINT TESTS

Item	From Page	Fastener Diameter Inches	T/D Ratio	No. Test		Hd. Style		Joint Type		Joint Material	
				Room	800°F	Prot	Flush	Lap	Butt	Bery	Alum & Bery
1	154	0.190	0.526	5			X	X		X	
2	154	0.190	0.526		4		X	X		X	
3	155	0.190	1.05	5			X		X		X
4	151	0.190	0.526	5		X		X		X	
5	151	0.190	0.526		5	X		X		X	
6	151	0.190	0.526	5		X			X	X	
7	151	0.190	0.526		4	X			X	X	
8	159	0.250	0.400	5			X	X		X	
9	159	0.250	0.400		5		X	X		X	
10	165	0.250	0.800	5			X		X		X
11	164	0.250	0.400	5		X		X		X	
12	164	0.250	0.400		4	X		X		X	
13	160	0.250	0.400	5		X			X	X	
14	160	0.250	0.400		5	X			X	X	
15	173	0.3125	0.642	5			X		X		X
16	169	0.3125	0.642	5		X			X		X

TABLE XXVI

LAP JOINT SINGLE SHEAR STRENGTH FLUSH HEAD POINT DRIVE BERYLLIUM BOLT IN BERYLLIUM SHEET MATERIAL

Item No.	Nom. Dia. In.	Temp °F	T/D Ratio	Permanent Set Offset Yield Strength per Bolt, Pounds					Ult. Load Lbs.
				.004	.006	.008	.010	.012	
1	0.190	Rm	0.526	1360	1500	1590	1650	(4) 1690	1980
2	0.190	800	0.526	(4) 710	(4) 830	(4) 880	(4) 910	(4) 930	(4) 1030
Bolt	(a)								
Single	0.190	Rm							Not
Shear	0.190	800							Tested
8	0.250	Rm	0.400	2140	(4) 2290	(3) 2380	(3) 2470	(3) 2530	2730
9	0.250	800	0.400	1340	1440	1470	1490	1510	1740
Bolt	(a)								
Single	0.250	Rm							4530
Shear	0.250	800							1770

1. One test.
2. Ave of two tests
3. Ave of three tests
4. Ave of four tests
5. Unless noted above, values are average of 5 tests.

(a) Values derived from double shear tests of bolts.

TABLE XXVII

LAP JOINT SINGLE SHEAR STRENGTH OF PROTRUDING HEAD POINT DRIVE BERYLLIUM BOLTS IN BERYLLIUM SHEET MATERIAL

Item No.	Nom Dia. In.	Temp °F	T/D Ratio	Permanent Set Offset Yield Strength Per Bolt, Pounds					Ult. Load Lbs.
				0.004	0.006	0.008	0.010	0.012	
4	0.190	Rm	0.526	1560	1670	1710	1790	1770	1770
5	0.190	800	0.526	840	900	930	950	970	1080
Bolt Single Shear	(a)								
	0.190	Rm							2070
	0.190	800							960
11	0.250	Rm	0.400	1550	(4) 1860	(4) 2060	(4) 2160	(4) 2230	2340
12	0.250	800	0.400	1290	1320	1380	1440	1470	1790
Bolt Single Shear	(a)								
	0.250	Rm							4530
	0.250	800							1770

TABLE XXVIII

BUTT JOINT SINGLE SHEAR STRENGTH OF PROTRUDING HEAD POINT DRIVE BERYLLIUM BOLT IN BERYLLIUM SHEET MATERIAL

Item No.	Nom. Dia. In.	Temp °F	T/D Ratio	Permanent Set Offset Yield Strength per Bolt, Pounds					Ult. Load Lbs.
				0.004	0.006	0.008	0.010	0.012	
6	0.190	Rm	.526	630	830	940	1010	1050	990
				(4)	(4)	(4)	(4)	(4)	(4)
7	0.190	800	.526	470	530	560	590	600	760
Bolt	(a)								
Single	0.190	Rm							2070
Shear	0.190	800							960
							(4)	(2)	
13	0.250	Rm	0.400	720	860	1020	1140	1210	1250
14	0.250	800	0.400	500	660	740	760	790	980
Bolt	(a)								
Single	0.250	Rm							4530
Shear	0.250	800							1770

TABLE XXIX

BUTT JOINT SINGLE SHEAR STRENGTH OF FLUSH HEAD POINT DRIVE BERYLLIUM BOLTS IN BERYLLIUM AND 7075-T6 ALUMINUM ALLOY SHEET MAT'L

Item No.	Nom. Dia. In.	Temp °F	T/D Ratio	Permanent Set Offset Yield Strength per Bolt, Pounds					Ult. Load Lbs.
				0.004	0.006	0.008	0.010	0.012	
10	0.250	Rm	0.800	1580	1950	2140	2300	2380	2560
Bolt	(a)								
Single	0.250	Rm							4530
Shear	0.250	800							1770
				(4)	(4)	(4)	(4)	(4)	
15	0.3125	Rm	0.642	1160	1570	1910	2200	2420	2830
Bolt	(a)								
Single	0.3125	Rm							6020
Shear	0.3125	800							2810

TABLE XXX

BUTT JOINT SINGLE SHEAR STRENGTH OF PROTRUDING HEAD POINT DRIVE BERYLLIUM BOLTS IN BERYLLIUM AND 7075-T6 ALUMINUM ALLOY SHEET MATERIAL

Item No.	Nom. Dia. In.	Temp °F	T/D Ratio	Permanent Set Offset Yield Strength per Bolt, Pounds					Ult. Load Lbs.
				.004	.006	.008	.010	.012	
3	0.190	Rm	1.05	1170	1300	1400	1470	1540	1650
Bolt Single Shear	(a)								
	0.190	Rm							Not
	0.190	800							Tested
16	0.3125	Rm	0.642	2200	2500	2800	2760	2900	3190
Bolt Single Shear	(a)								
	0.3125	Rm							6020
	0.3125	800							2810

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SECTION VIII

CONCLUSIONS

For the work conducted in this program, the following conclusions were drawn:

A. Materials

1. Berylco XT-20 material was considered as the optimum material for fabrication into fasteners because of its availability and excellent tensile and shear properties. It would not, however, be acceptable by Standard Pressed Steel Co. standards for producing high reliability beryllium bolts. On the other hand, satisfactory hexagon nuts can be manufactured from this material.

2. The various beryllium materials evaluated did not possess the forging characteristics required for optimum fastener application.

3. A minimum of 0.002 inch surface removal by chemically etching was required for optimum shear properties.

B. Prestressed Fastener System

1. Design

a. Satisfactory beryllium point drive bolts in both a protruding and 100° flush head configuration were designed and manufactured.

B. 1. Design (continued)

b. A companion twist-off nut of 347 stainless steel was designed and manufactured for #10-32, 1/4-28 and 5/16-24 bolt sizes to give adequate clamping force for beryllium fastener application.

2. Fabrication

a. Standard tooling used for the fabrication of steel fasteners was satisfactory for the fabrication of beryllium fasteners.

b. Forward extruding a head on beryllium was feasible for fastener application. However, it does present certain limitations when compared to forging or hot upsetting a head. Foremost among these would be the high scrap rate followed by lower head strength, limited bolt length and type of head configuration that can be formed.

c. Centerless grinding employing a water soluble coolant does not cause severe surface damage and would be recommended for close tolerance work.

d. Rolled threads would be required for optimum fatigue properties.

e. Rolled threads in the unetched condition did not have an adverse effect on the bolt tensile and fatigue properties. However, threads with etched surfaces would be recommended to eliminate any surface defects.

3. Testing

a. Tensile strength of installed fasteners was inconsistent. This was attributed to cracks in the thread area that extended below the pitch diameter.

B. Testing (continued)

b. Beryllium fasteners were not notch sensitive at 800°F.

c. Double shear strength of fasteners will exceed the target requirements of 65,000 psi.

d. Beryllium lap joints were significantly stronger than beryllium butt joints at room and 800°F temperatures. A logical explanation for this higher strength is not known at the present time.

e. Corrosion resistant properties of beryllium with etched surfaces would be similar to aluminum material with untreated surfaces.

C. Blind Fastener System

1. Design

a. A beryllium blind fastener was designed and developed that would meet the objectives of the contract; namely, a light weight blind fastener system capable of being installed into a beryllium structure from one side and able to be used in temperature application approaching 800°F.

b. More development work would be required prior to the designing of a gun-type installation tool.

2. Fabrication

Carbide type rifle drills are not necessary for drilling deep holes in beryllium sleeve components. C-2 two fluted drills were used successfully in drilling these holes.

3. Testing

a. The double angle on the tip of the beryllium sleeve was essential for developing a preload on the structural material into which the beryllium blind bolt was installed.

C. 3. Testing (continued)

b. The tensile strength of the beryllium blind bolt is entirely dependent on the column strength of the stainless steel collar.

c. The double-shear strength of the beryllium blind bolt was approximately one-half that of a solid beryllium fastener. The shear strength could be increased by using extruded material for the sleeve portion of the assembly.

SECTION IX

RECOMMENDED AREAS FOR FUTURE WORK

MATERIALS

1. It is recommended that headed fasteners be manufactured from beryllium materials capable of meeting the requirements of the SPS Proposed Beryllium Specification outlined in the Appendix (Page 191).

2. Fasteners

   a. Additional development work would be required for fabricating the latest Brush material into prestressed and blind fasteners. However, this would primarily be in the testing area to establish mechanical properties. Manufacturing processes and controls were sufficiently established during this program.

   Fasteners presently being made by the Precision Fastener Division of Standard Pressed Steel Co. from the Brush Forgeable Grade Material are shown in Figure 70.

TESTING

The work in this program showed that a beryllium lap joint was much stronger than a beryllium butt joint. However, the reason for this superior strength was not resolved. A program should be initiated to further explore the area of joint strength. Included in the program should be the evaluation of beryllium joints in comparison with other joint materials such as aluminum.

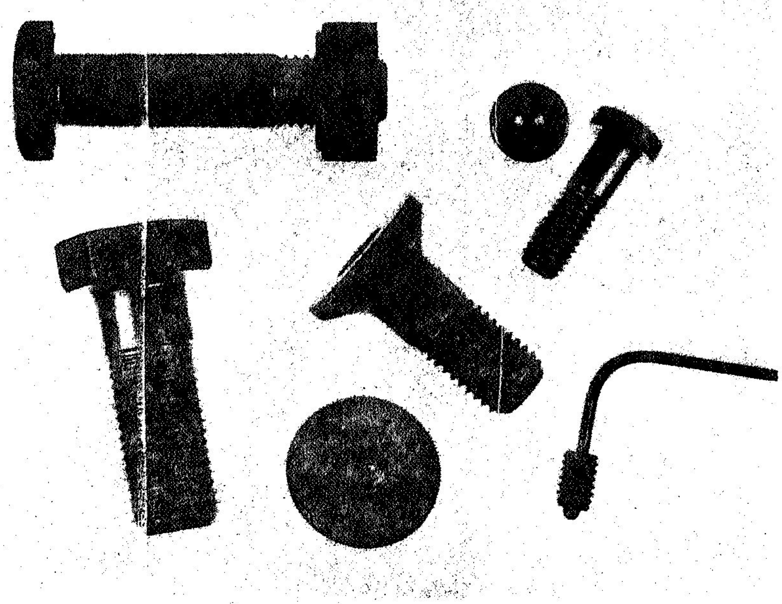

Figure 70. Representative Photograph of Beryllium Fasteners Presently Manufactured by the Precision Fastener Division of the Standard Pressed Steel Co.

SECTION X

REFERENCES

1. Gowen, Edward F. Jr.: "Beryllium Fasteners", AMC Technical Report 60-7-807, August 1960

2. Gowen, Edward F. Jr.: "Beryllium Shear Bolts, Flush Head BFT 12 and BFH 12 - Protruding Head BHS 12 - 60,000 Psi Minimum Shear Strength" SPS Laboratory Report No. 397 January 30, 1961

3. Soled, J.: Fasteners Handbook, Reinhold Publishing Corporation 430 Park Ave., New York, U.S.A.

4. Fasteners: Machine Design, Reference Issue, A Penton Publication, March 11, 1965

5. Williams, R.F. and Ingels, S.E. "The Fabrication of Beryllium" Volume III and NASA Technical Memorandum, NASA TM-53453, July 1966.

APPENDIX

SPS PROPOSED BERYLLIUM SPECIFICATION

SPS T-147 SPECIFICATION - SCREW THREADS - 55%

BERYLLIUM JOINT LOAD CURVES

SPS MATERIAL SPECIFICATION

BERYLLIUM
(FORGING GRADE)

TENTATIVE

PROJECT NO.

1. SCOPE

1.1 This specification covers the requirements for beryllium alloy suitable for hot upsetting. The material is designed primarily for fasteners requiring light weight, high modulus of elasticity, high specific heat and good thermal conductivity.

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on the date of initiation of purchase order form a part of this specification to the extent specified herein.

Specifications and Standards

Military

XWS 6917	Naval Ordnance - Beryllium bars, rods, and shapes
XWS 8246	Naval Ordnance - Beryllium material
MIL-I-6866	Inspection, Penetrant Method
MIL-STD-453	Military Standard, Inspection Radiographic

Federal Standards

No. 151 Federal Test Methods Standards - Metals; Test Method

USA Standards Institute

B46.1 Surface Texture

American Society for Testing and Materials

ASTM-B311 Standard Method of Testing for Density of Cemented Carbides

REVISED Proposed 1-8-68

DATE APPROVED

STANDARD PRESSED STEEL CO. SPS JENKINTOWN PENNSYLVANIA	SPS STANDARDS	SPS-M-576
	BERYLLIUM	
	(FORGING GRADE)	Sheet 1 of 6

3. REQUIREMENTS

3.1 Chemical Composition shall meet the requirements of Table 1 when tested per Para. 4.1.

TABLE 1

Element	Analysis % Min.	Analysis % Max.
Beryllium	98.00	
Beryllium Oxide		2.00
Aluminum		.20
Carbon		.15
Iron		.20
Magnesium		.08
Silicon		.12
Other Metallic Impurities (each)		.04

3.2 Condition - Must be homogeneous, free from segregation or any other internal or external defects which would be detrimental to the manufacturing process or products.

3.2.1 The blanks for extruded rod shall be produced by hot pressing a blend of virgin powder of minus 200 mesh size and recycled powder of minus 200 mesh size.

3.2.2 Extruded rod shall have an etched surface with at least a 125 micro inch finish per USA Standard B46.1. Material shall be free from seams, slivers, grooves or other surface imperfections.

3.2.3 All surfaces and edges shall be free from cracks. Surface porosity, as detected by penetrant inspection per Para. 4.2 is acceptable provided no individual pore exceeds .005 in. in its greatest dimension.

3.2.4 The extruded rod shall conform to the tolerances listed on Table 2.

TABLE 2

Rod Diameter	Tolerance, Inches
Up to .250	+.005 -.000
Over .250 to .500	+.006 -.000
Over .500 to 1.000	+.010 -.000

3.3 Metallurgical Requirements

3.3.1 The rod material shall have a minimum density of 1.84 grams per cubic centimeter when tested per Paragraph 4.4.

3.3.2 The average grain size in the transverse section of the rod shall not exceed 30 microns when tested per Paragraph 4.5.

3.3.3 No individual indications either as a high density inclusion or a void shall exceed .005 in. in thickness and .075 in. in length when radiographic inspection per Paragraph 4.6 is performed.

3.3.4 The extruded rod shall be capable of being hot upset (900-1500°F) in an unclad condition to the dimensions of Figure 1 and meet the following crack requirements when tested per Para. 4.7.

3.3.4.1 Bearing face - no cracks to originate in the bearing face.

3.3.4.2 Fillet - no cracks in the fillet.

3.3.4.3 Top - no cracks are allowed to originate in the top surface.

3.3.4.4 Upset circumference - no more than 4 cracks penetrating the top area deeper than .010. No cracks shall penetrate deeper than .025.

3.4 Mechanical Properties - The material shall meet the tensile and double shear requirements of Table 3 when tested per Paragraph 4.8.

TABLE 3

Ultimate Tensile	95,000 PSI Minimum
Yield Strength .2% Offset	45,000 PSI Minimum
Elongation (4D length)	5% Minimum
Double Shear	65,000 PSI Minimum

3.5 Approval

3.5.1 Source Approval - Production material shall be purchased only from those vendors who have supplied test material meeting all of the requirements of this specification. The vendor's facilities shall be surveyed before making routine production purchases.

4. QUALITY ASSURANCE PROVISIONS

4.1 The chemical composition shall be determined by the Federal Test Method Standard No. 151.

4.2 Rods will be 100% penetrant inspected per MIL-I-6866 and examined for surface defects.

4.3 Straightness - The straightness of rod shall be determined by supporting the rod in vee blocks at each end. No more than 1/2 inch shall bear on the block at each end. An indicator placed midway between the supports will measure the extreme variation as the rod is revolved on the vee block. The straightness of the bar shall conform to the tolerances listed in Table 4.

TABLE 4

Rod Length	Total Indicator Reading (inches)
Up to 18 inches	0.020
Over 18 inches to 48 inches	0.025

4.4 The material density shall be determined to an accuracy of $\pm$.5% by ASTM Standard Test Method B311, except full diameter rod may be used in place of standard size laboratory specimens.

4.5 The grain size shall be determined per ASTM-E112 Section 7b.

4.6 Rods will be 100% radiographic inspected per MIL-Std-453. Indication depths shall be measured perpendicular to the longitudinal axis of the rod.

4.7 Upset Test

4.7.1 A blank shall be cut from the rod and chemically milled to remove .003 in. from the surface. The finished blank shall have a length equal to 4 times the diameter.

4.7.2 The blank will be forged within closed dies using a drop press as a forming device to produce the configuration of Figure 1. The temperature shall be selected between 900 and 1500°F to provide the best upset. The vendor may recommend the forging temperature.

4.7.3 The depth of the cracks in the upset part shall be determined by metallographic procedures.

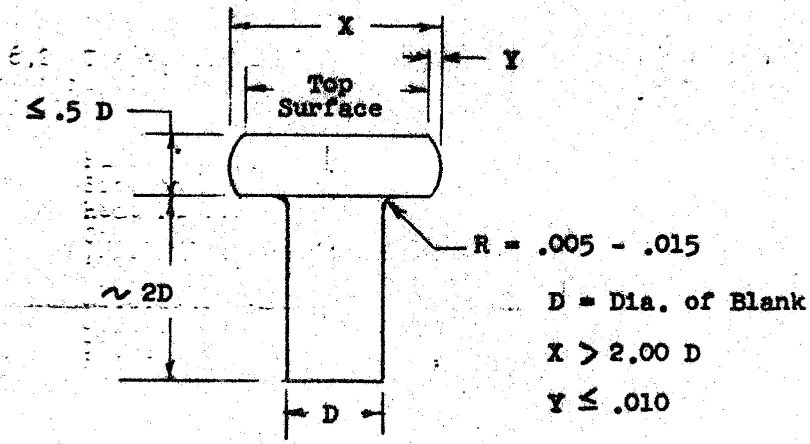

FIGURE 1

4.8 Mechanical Test

4.8.1 Tensile test shall be conducted on specimens per SPS Lab Report No. 72 except the strain rate shall be maintained at .003-.007 inches per inch per minute.

4.8.2 The double shear load shall be the value at which there is an initial drop in load in conjunction with an indentation of the specimen by the dies. A ductile shear fracture is required for all specimens. The test fixtures and method are per SPS Lab Report No. 72.

5. PREPARATION FOR DELIVERY

5.1 The material shall be packaged in such a manner as to assure delivery of the material maintianing the requirements of this specification.

5.2 Individual pieces or bundles shall have attached a metal tag stamped with the purchase order number, specification number, nominal diameter, heat number, or shall be boxed and the box marked with the same information.

6. REPORTS

6.1 Lots - A lot consists of all rods of one size of one heat of material shipped at one time.

6.2 The vendor shall furnish three copies of a certified report of test results for each lot shipped. The report shall include the following:

Purchase Order Number
Size and Quantity
Heat Number
Chemical Analysis
Average Grain Size
Material Specification Number
Mechanical Properties
Density
Radiographic and Penetrant Inspection Certification

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SPS SPECIFICATION

SCREW THREADS 55%

1. Scope

1.1 Scope - This specification establishes the requirements for 55% Screw Threads for use where reduction of thread stress concentration is necessary.

2. Applicable Publications - The following documents and the latest revisions thereof shall form a part of this specification to the extent specified herein.

2.1 MIL-S-7742 Screw Threads, Standard, Aeronautical
MIL-S-8879 Screw Threads, Controlled Radius Root with Increased Minor Diameter, General Specification for.

3. Requirements

3.1 Form, Dimensions, and Tolerance - The form, dimensions, tolerance, and contour of the threads shall conform to specification MIL-S-7742 except as modified herein.

3.1.1 Modification of Root - The root of the 55% Thread shall consist of a radius blending with the thread flanks at a gage interference point of 55% to 62% of Unified and American basic thread depth as shown in Figure 1. The root radius shall conform to the values listed in Table I.

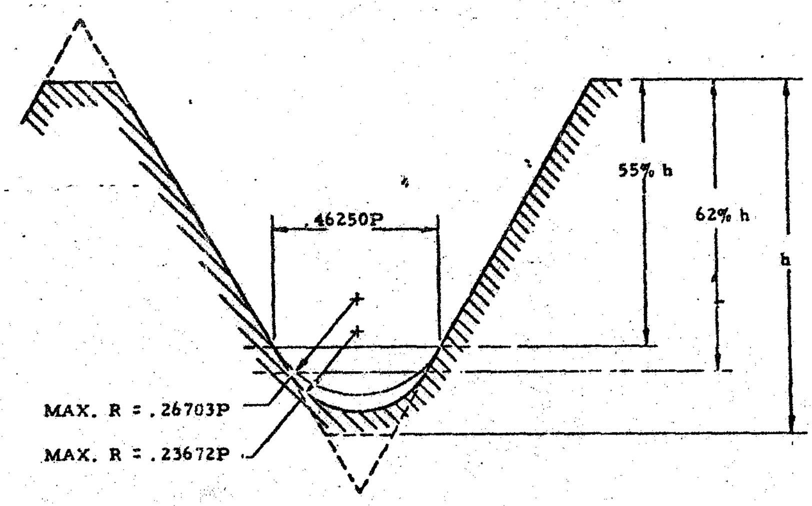


FIGURE 1. MODIFIED ROOT FOR 55% THREADS

DATE APPROVED 10/18/60 REVISED

STANDARD PRESSED STEEL CO. SPS JENKINTOWN PENNSYLVANIA	SPS STANDARDS	SPS-T-147
	SCREW THREADS, 55%	
	SPS ENGINEERING DEPARTMENT	

TABLE I.
THREAD ROOT RADIUS

PITCH	ROOT RADIUS MAX.	ROOT RADIUS MIN.
40	.0067	.0059
32	.0083	.0074
28	.0095	.0085
24	.0111	.0099
20	.0134	.0118

PITCH	ROOT RADIUS MAX.	ROOT RADIUS MIN.
18	.0148	.0132
16	.0167	.0148
14	.0191	.0169
12	.0223	.0197

The radii for thread pitches not listed in the above table can be computed as follows:

Max. radius equals .26703 pitch and Min. radius equals .23672 pitch.

3.1.2 Internal Thread - The internal thread to be mated with the 55% Thread shall be modified at the minor diameter so that the maximum depth of thread shall be 55% of the basic thread height as shown in Figure 2.

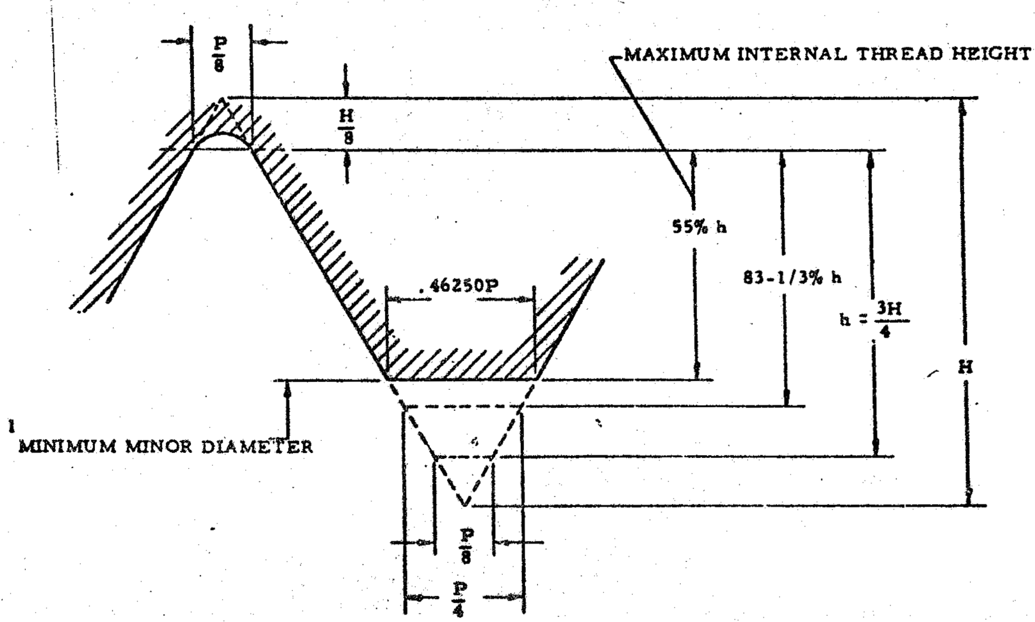


FIGURE 2. INTERNAL THREAD
[1] MINIMUM MINOR DIAMETER EQUALS BASIC MAJOR DIAMETER MINUS .71448P

3.2 Gages - All 55% screw-thread gages shall conform to MIL-S-7742 and MIL-S-8879 except that the gages for external threads shall have the minor diameter increased sufficiently to accept a maximum thread engagement depth of .41250H.

4. INSPECTION.

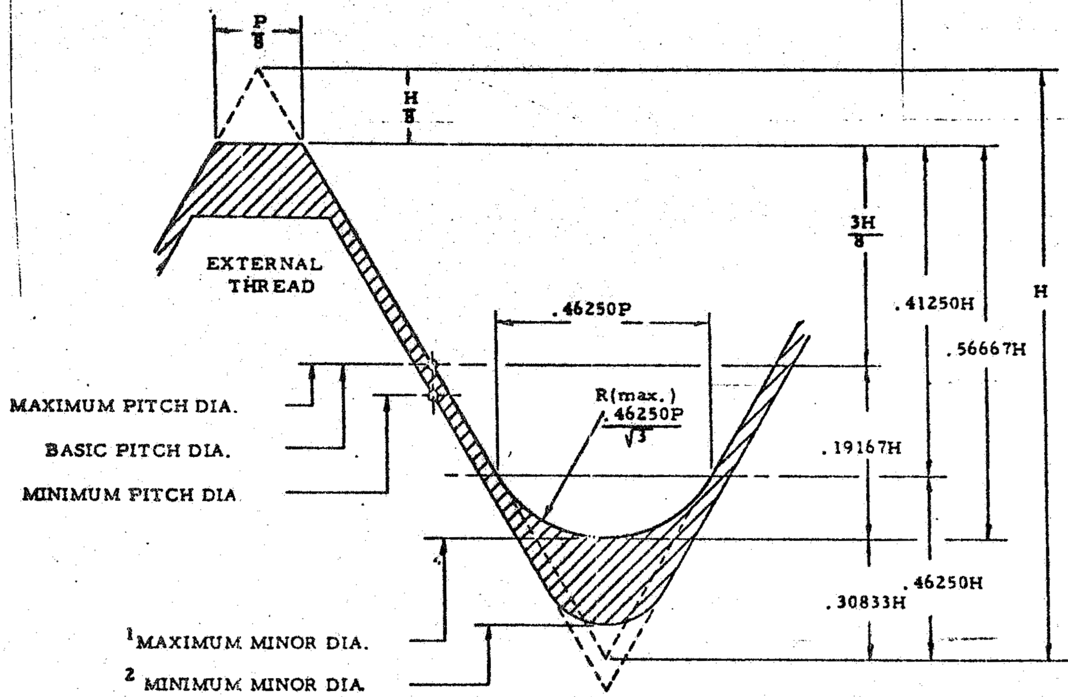
4.1 55% screw threads shall be inspected for conformance with the requirements of this specification and MIL-S-7742 as applicable. The amount and method of inspection shall be determined by the applicable product specification.

5. THREAD DESIGNATION

5.1 55% threads shall be designated in accordance with MIL-S-7742 except that the term 55% shall be affixed to the end of the thread call-out.

Example: 1/2-20 UNF-3A-55%

THREAD FORM AND FORMULAE
(MAXIMUM METAL CONDITION)



1. MAXIMUM MINOR DIAMETER = MAXIMUM PITCH DIAMETER -.33198P
2. MINIMUM MINOR DIAMETER = MINIMUM PITCH DIAMETER - 39260P

TABLE II
THREAD DATA, HI R THREAD FORM
(MAXIMUM METAL CONDITION)

THREADS PER INCH	PITCH	HEIGHT OF SHARP "V" H	THREAD HEIGHT .56667H	FLAT AT CREST $\frac{P}{8}$	TRUNCATION OF CREST $\frac{H}{8}$	TRUNCATION OF ROOT .30833H	ADDENDUM $\frac{3H}{8}$	.19167H
40	.02500	.02165	.01227	.00313	.00271	.00668	.00812	.00415
32	.03125	.02706	.01533	.00391	.00338	.00834	.01015	.00519
28	.03571	.03093	.01753	.00445	.00387	.00954	.01160	.00593
24	.04167	.03608	.02045	.00521	.00451	.01112	.01353	.00692
20	.05000	.04330	.02454	.00625	.00541	.01335	.01624	.00830
18	.05556	.04811	.02726	.00694	.00601	.01483	.01804	.00922
16	.06250	.05413	.03067	.00781	.00677	.01669	.02030	.01037
14	.07143	.06186	.03505	.00893	.00773	.01907	.02320	.01186
12	.08333	.07217	.04090	.01042	.00902	.02225	.02705	.01383

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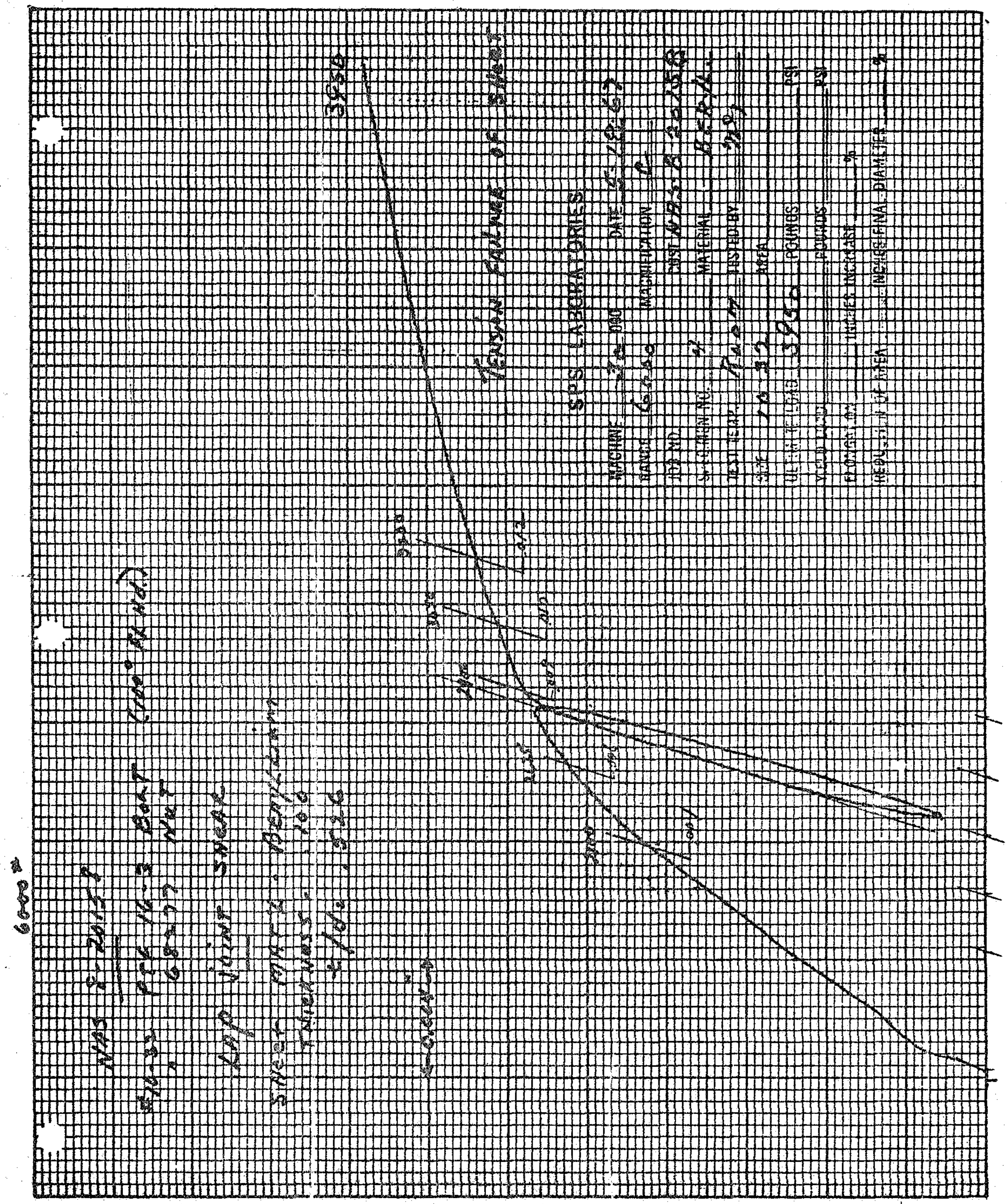
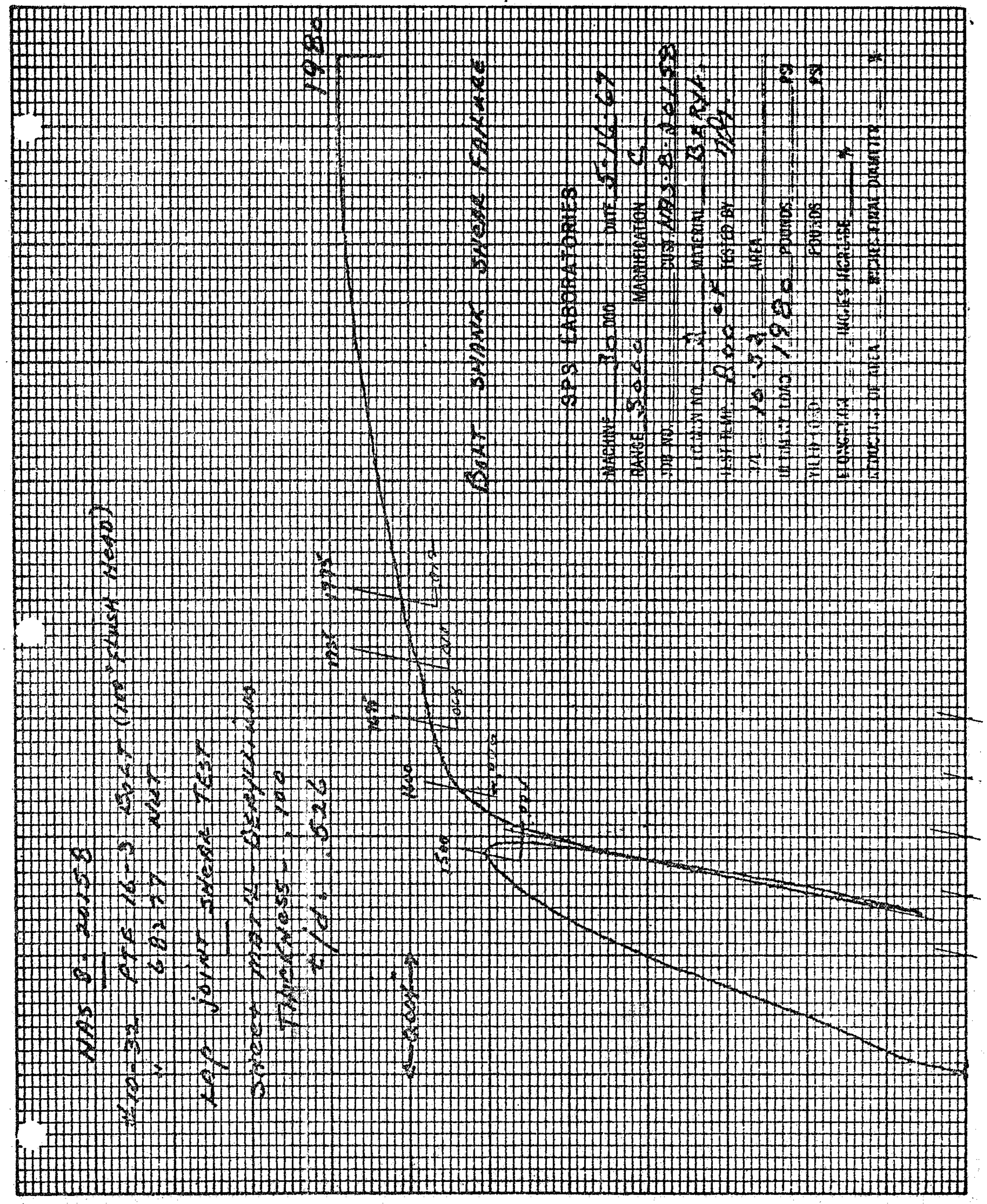
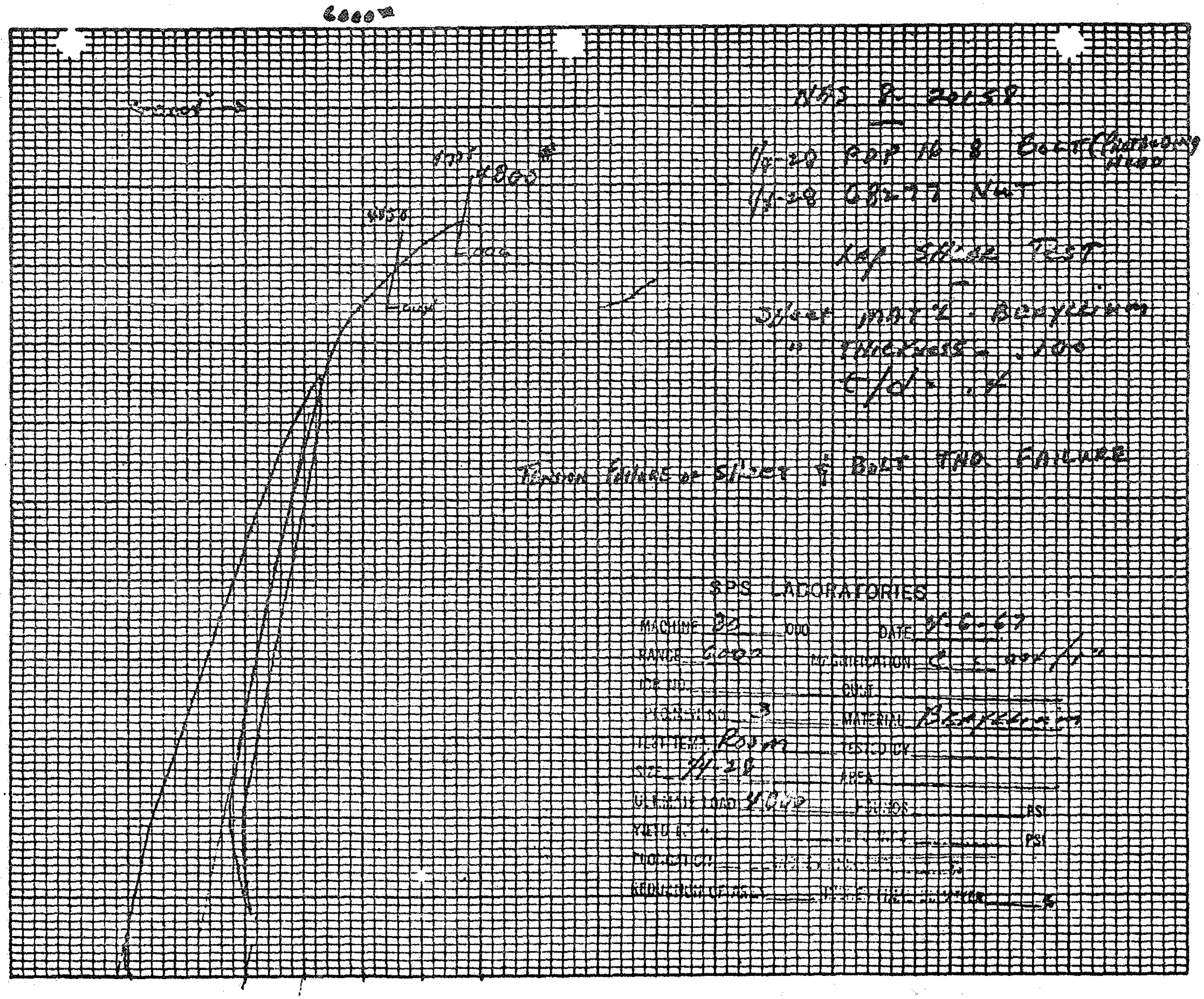
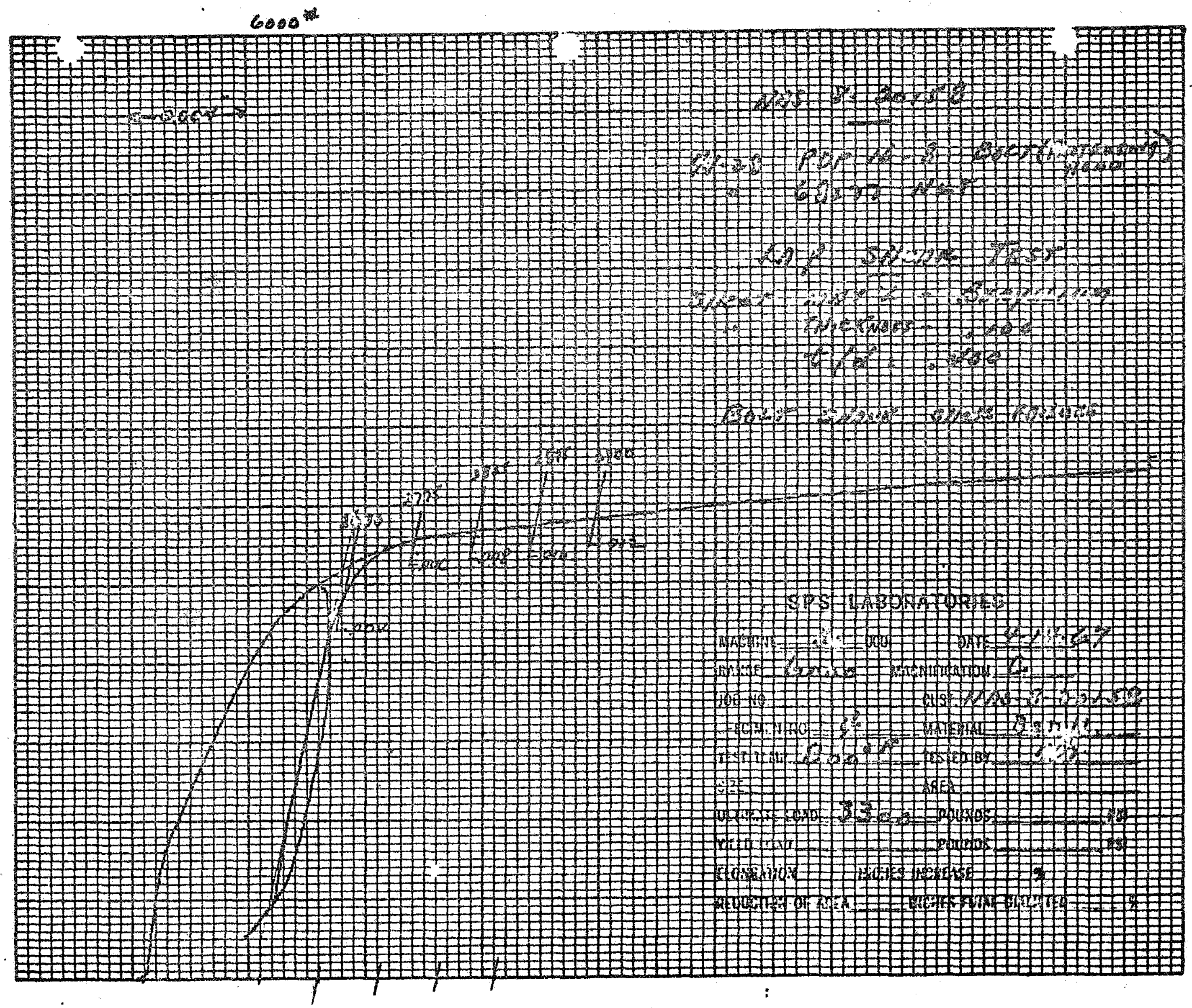
BERYLLIUM LAP JOINT

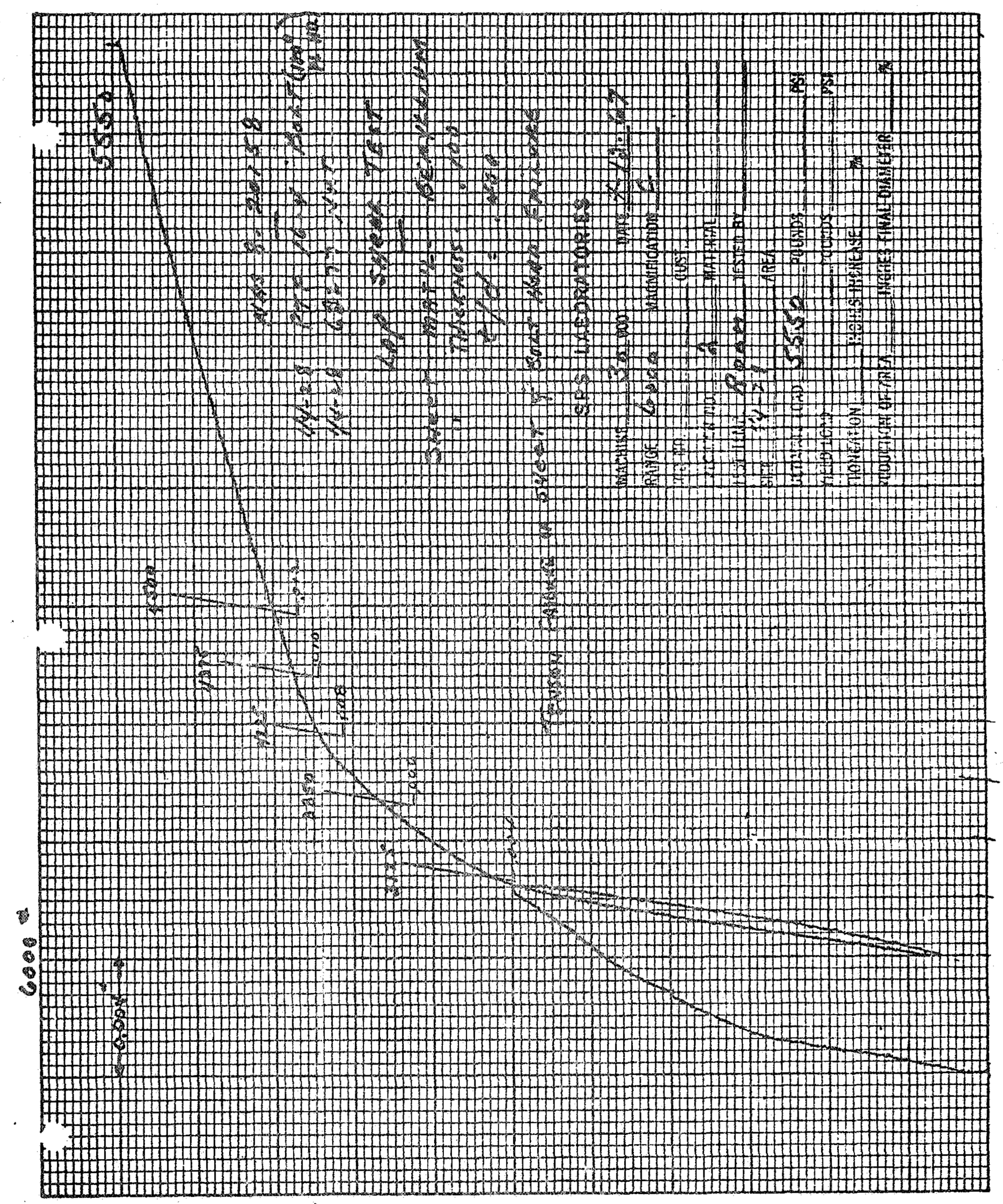
LOAD CURVES

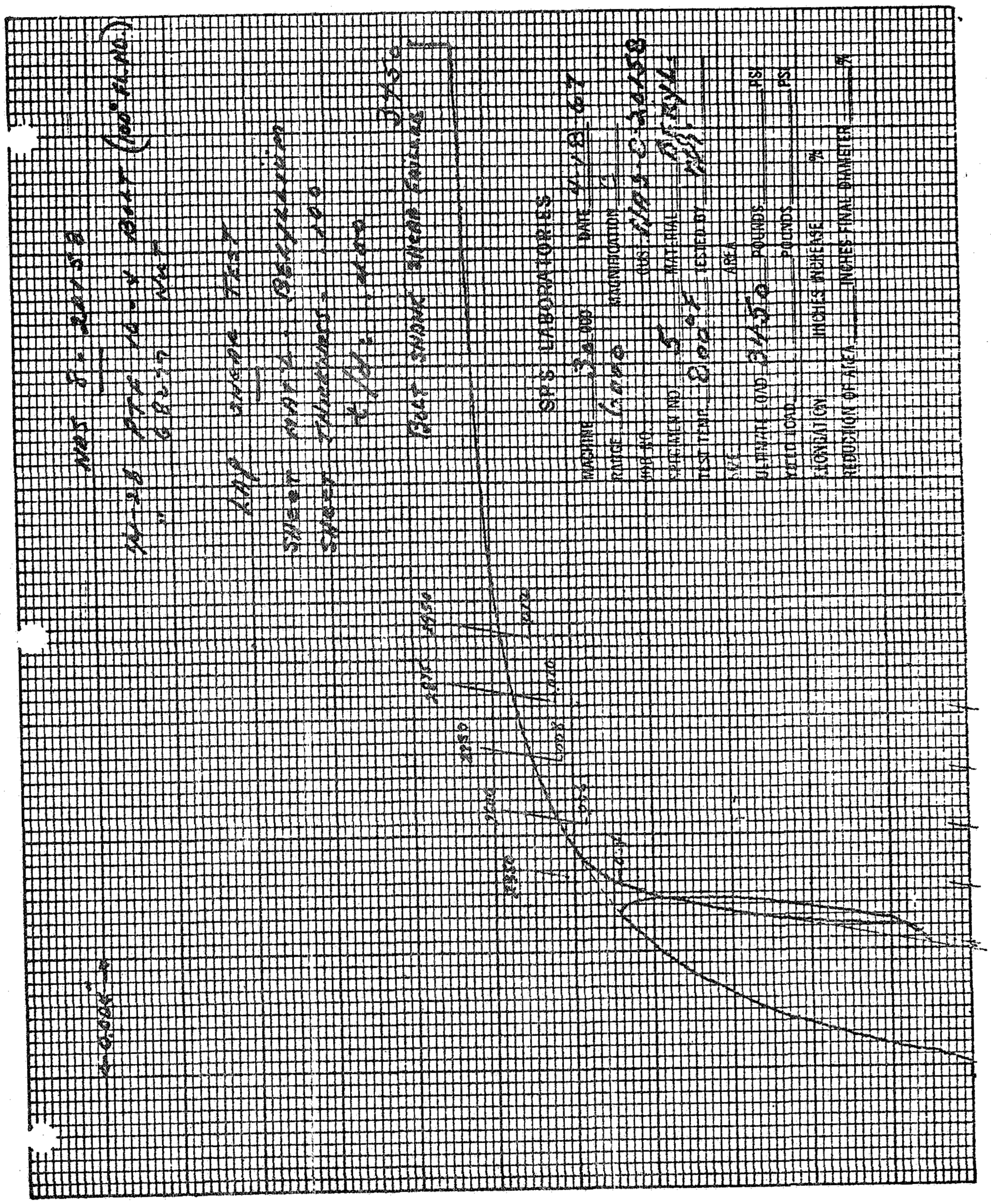

6000#
NAS 8-20158
#10-32 PTL 16-3 BOLT (1800° F.L. Hd.)
68277 NUT
LAP JOINT SHEAR
SHEET MAT'L - BERYLLIUM
THICKNESS - .100
e/d = .526
0.004
3950
TENSION FAILURE OF SHEET
SPS LABORATORIES
MACHINE 30,000
DATE 5-18-67
RANGE 6000
MAGNIFICATION
JOB NO.
COST NAS-8-20158
SPECIMEN NO. 4
MATERIAL BERYL.
TEST TEMP. ROOM
TESTED BY
SIZE 10-32
AREA
ULTIMATE LOAD 3950 POUNDS
PSI
YIELD LOAD
POUNDS
PSI
ELONGATION
INCHES INCREASE
%
REDUCTION OF AREA
INCHES FINAL DIAMETER
%


NAS 8-20158
#10-32 PTE 16-3 BOLT (100° FLUSH HEAD)
" 68277 NUT
LAP JOINT SHEAR TEST
SHEET MAT'L - BERYLLIUM
THICKNESS - .100
t/d = .526
1980
BOLT SHANK SHEAR FAILURE
SPS LABORATORIES
MACHINE 30,000 DATE 5-16-67
RANGE 5000 MAGNIFICATION C
JOB NO. CUST. NAS 8-20158
LOCATION NO. 2 MATERIAL BERYL.
TEST TEMP. 800 °F TESTED BY
ULTIMATE LOAD 1980 POUNDS PSI
YIELD LOAD POUNDS PSI
ELONGATION INCHES INCREASE %
REDUCTION OF AREA INCHES FINAL DIAMETER %


6000#
4800#
4450
NAS 9-20158
1/4-28 PDP 16-8 BOLT (PROTRUDING HEAD)
1/4-28 CB277 NUT
LAP SHEAR TEST
SHEET MAT'L - BERYLLIUM
" THICKNESS - .100
t/d - .4
TENSION FAILURE OF SHEET & BOLT THD. FAILURE
SPS LABORATORIES
MACHINE
DATE 11-6-67
RANGE 6000
MATERIAL BERYLLIUM
TEST TEMP. ROOM
SIZE 1/4-28
ULTIMATE LOAD 4800
PSI
PSI


6000#
SPS LABORATORIES
MACHINE
DATE
RANGE
MAGNIFICATION
JOB NO.
CUST.
SPECIMEN NO.
MATERIAL
TEST TEMP.
TESTED BY
SIZE
AREA
ULTIMATE LOAD 3300 POUNDS PSI
YIELD LOAD POUNDS PSI
ELONGATION INCHES INCREASE %
REDUCTION OF AREA INCHES FINAL DIAMETER %


6000
5550
LAP SHEAR TEST
SHEET MAT'L - BERYLLIUM
SPS LABORATORIES
MACHINE 30,000
DATE
RANGE 6000
MAGNIFICATION
CUST.
MATERIAL
TESTED BY
AREA
ULTIMATE LOAD 5550 POUNDS PSI
YIELD LOAD POUNDS PSI
ELONGATION INCHES INCREASE %
REDUCTION OF AREA INCHES FINAL DIAMETER %


NBS 8-20158
1/4-28 PTF 16-X BOLT (100° FL.HD.)
" 6B277 NUT
LAP SHEAR TEST
SHEET MAT'L - BERYLLIUM
SHEET THICKNESS - .100
t/D: .400
BOLT SHANK SHEAR FAILURE
3450
SPS LABORATORIES
MACHINE 30,000
DATE 4-18-67
RANGE 6000
MAGNIFICATION
JOB NO.
CUST. NAS-C-20158
SPECIMEN NO. 5
MATERIAL BERYL.
TEST TEMP. 800°F
TESTED BY
SIZE
AREA
ULTIMATE LOAD 3450 POUNDS PSI
YIELD LOAD POUNDS PSI
ELONGATION INCHES INCREASE %
REDUCTION OF AREA INCHES FINAL DIAMETER %

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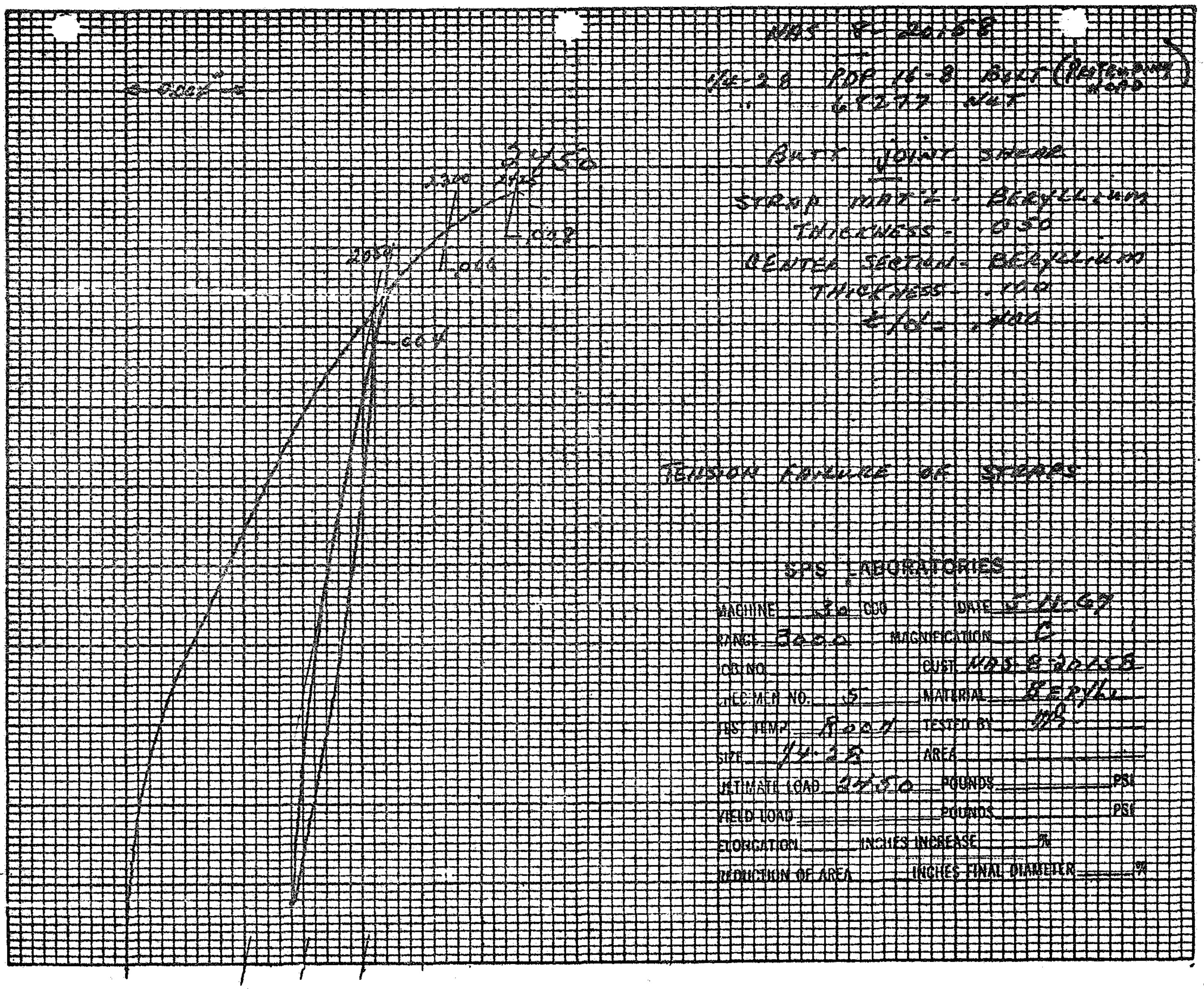
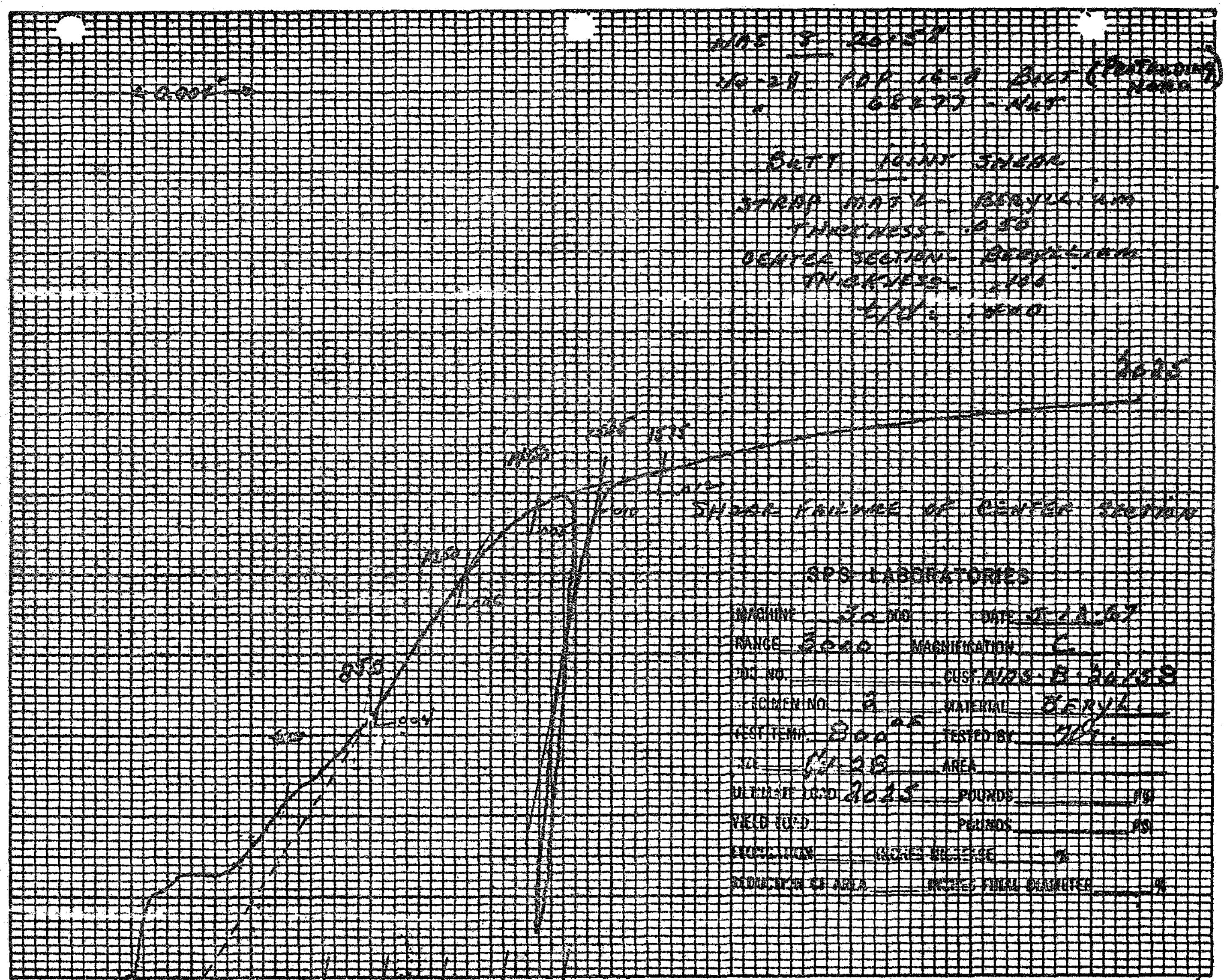
BERYLLIUM BUTT JOINT LOAD CURVES


NBS 8-20158
HL-28 PDP 16-8 BUTT (RESTRAINING WOOD)
" 68277 NUT
BUTT JOINT SHEAR
STRAP MAT'L - BERYLLIUM
THICKNESS - .050
CENTER SECTION - BERYLLIUM
THICKNESS - .100
E/D - .400
TENSION FAILURE OF STRAPS
2450
2425
2300
2050
.009
.022
.016
.004
SPS LABORATORIES
MACHINE 30 000
DATE 5-11-67
RANGE 3000
MAGNIFICATION C
JOB NO.
CUST. NBS 8-20158
SPECIMEN NO. 5
MATERIAL BERYL
TEST TEMP. ROOM
TESTED BY MB
SIZE HL-28
AREA
ULTIMATE LOAD 2450 POUNDS PSI
YIELD LOAD POUNDS PSI
ELONGATION INCHES INCREASE %
REDUCTION OF AREA INCHES FINAL DIAMETER %


BUTT JOINT SHEAR
SHEAR FAILURE OF CENTER SECTION
SPS LABORATORIES
MACHINE
DATE
RANGE 5000
MAGNIFICATION
CUST
SPECIMEN NO.
MATERIAL
TEST TEMP.
TESTED BY
AREA
ULTIMATE LOAD 2025
POUNDS
PSI
YIELD LOAD
ELONGATION
INCHES INCREASE
%
REDUCTION OF AREA
INCHES FINAL DIAMETER
2025

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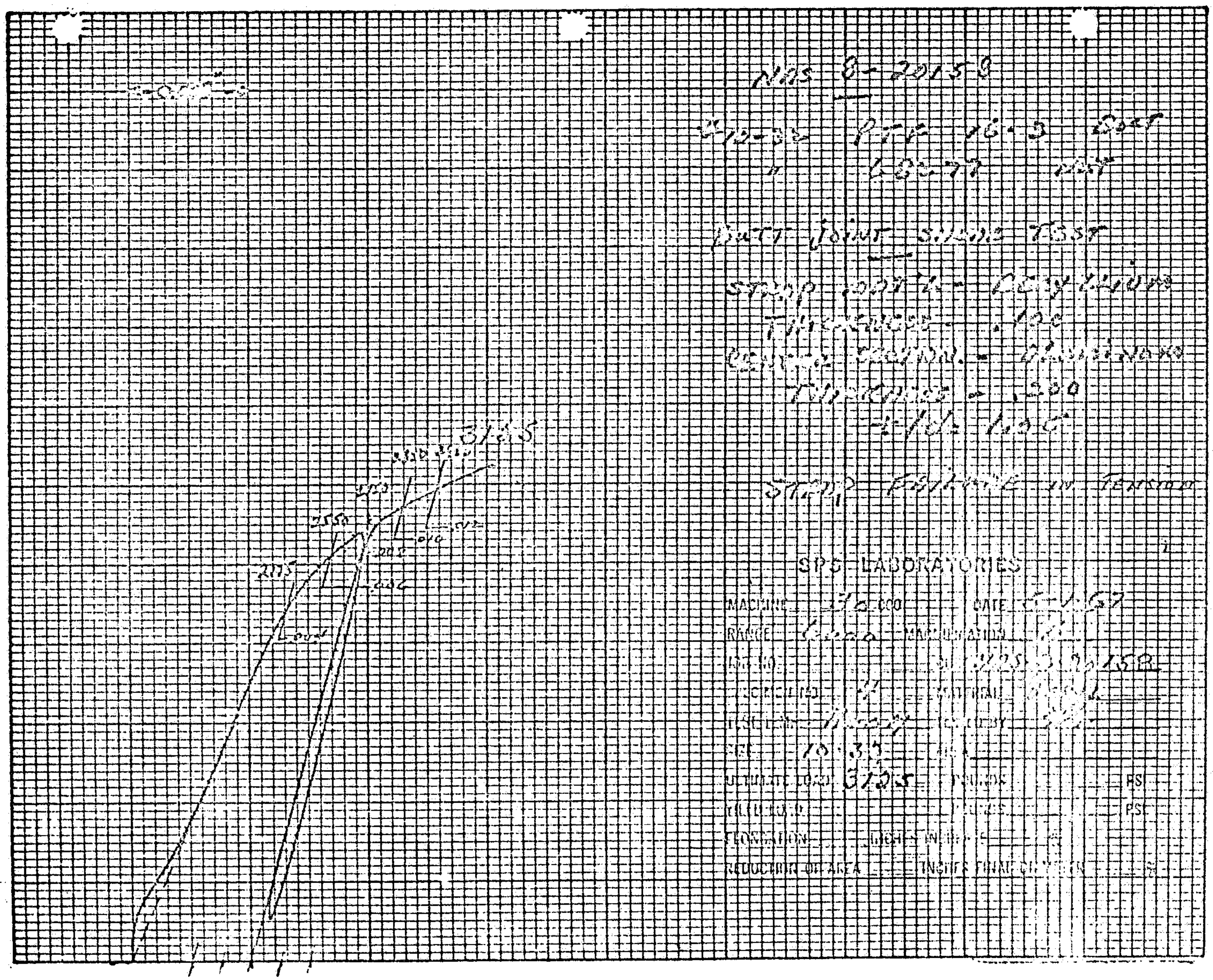
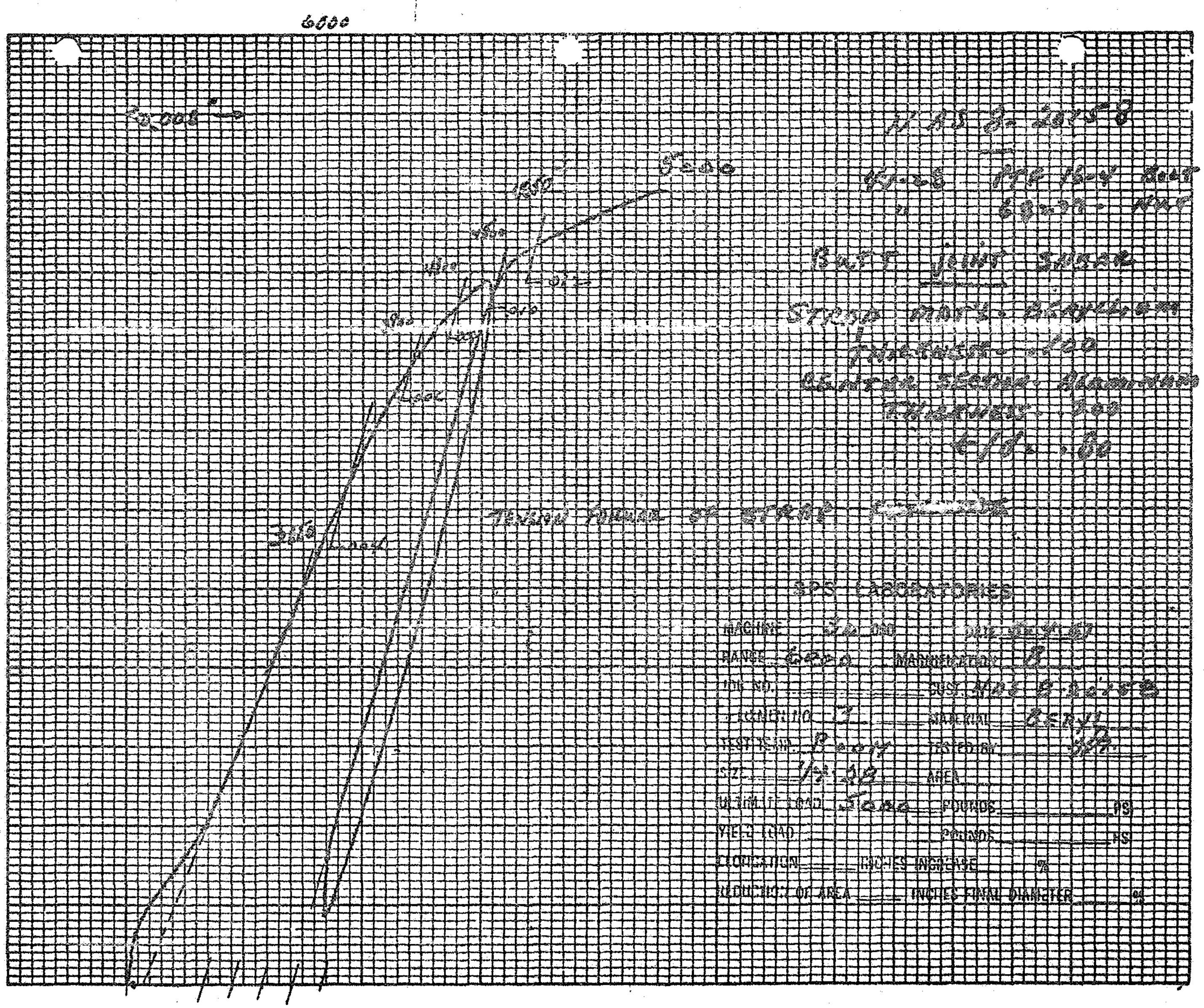
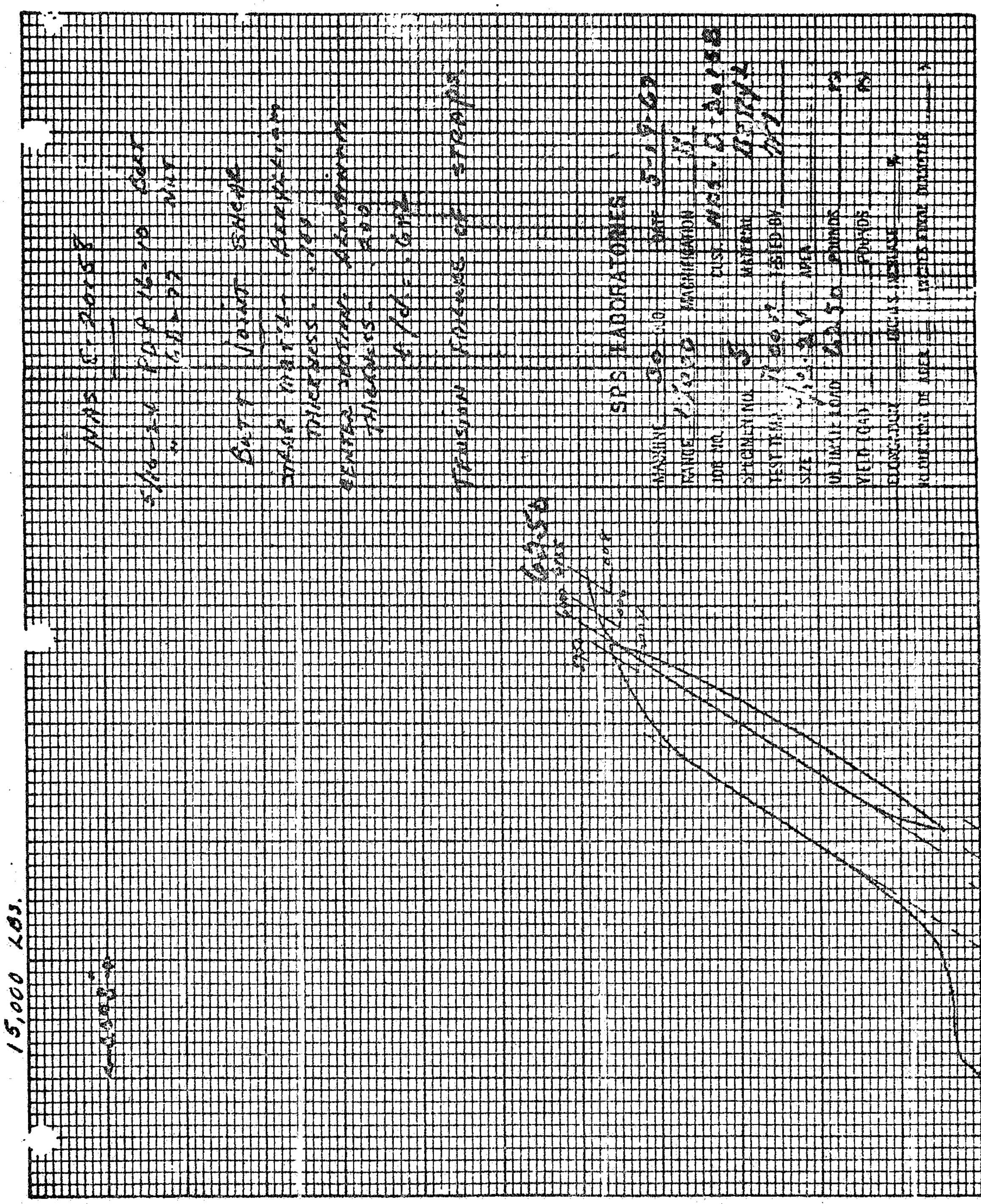
BERYLLIUM-ALUMINUM BUTT JOINT LOAD CURVES



NAS 8-20158
BUTT JOINT SHEAR TEST
STRAP FAILURE IN TENSION
SPS LABORATORIES
MACHINE
DATE
RANGE
MAGNIFICATION
MATERIAL
10.35
ULTIMATE LOAD 3725 POUNDS
PSI
YIELD LOAD
PSI
ELONGATION
INCHES IN
REDUCTION OF AREA
INCHES FINAL
3725
LOAD


6000
5000
Butt Joint Shear
Tension Failure of Strap
SPS LABORATORIES
MACHINE
DATE
RANGE 6000
MAGNIFICATION 8
JOB NO.
CUST.
SPECIMEN NO. 3
MATERIAL
TEST TEMP. Room
TESTED BY
SIZE
AREA
ULTIMATE LOAD 5000 POUNDS PSI
YIELD LOAD POUNDS PSI
ELONGATION INCHES INCREASE %
REDUCTION OF AREA INCHES FINAL DIAMETER %


15,000 LBS.
NAS 8-20158
5/16-24 PDP 16-10 BOLT
BUTT JOINT SHEAR
STRAP MAT'L - BERYLLIUM
THICKNESS - .189
CENTER SECTION - ALUMINUM
THICKNESS - .200
TENSION FAILURE OF STRAPS
6250
SPS LABORATORIES
MACHINE
DATE 5-19-60
RANGE
MAGNIFICATION
JOB NO.
CUST.
SPECIMEN NO. 5
MATERIAL
TEST TEMP.
TESTED BY
SIZE
AREA
ULTIMATE LOAD 6250 POUNDS
YIELD LOAD POUNDS
ELONGATION INCHES INCREASE %
REDUCTION OF AREA INCHES FINAL DIAMETER %